'GLOBAL CROP PRODUCTION FORECASTING'

AN ANALYSIS OF THE DATA SYSTEM PROBLEMS AND THEIR SOLUTIONS

FINAL REPORT

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

With the launch of the first Earth Resources Technology Satellite (ERTS)* on July 23, 1972, a new era of direct application of space technology to human needs began. Since that time, the usefulness of the multispectral image data obtained from the Landsat series of satellites has been demonstrated for aiding natural resource management. The ability to obtain synoptic measurements of systems spread over wide geographic areas offers an advantage over many traditional data taking approaches. Other advantages include easy access to data over inaccessible regions and economical frequent updates. Recent studies and programs such as Sigma Squared (1), Large Area Crop Inventory Experiment (2), and others (3), (4), (5) indicate remotely sensed data will be useful for agricultural forecasting.

As experiments (6) and studies such as Optimum Repeat Cycle Analysis (7) are identifying and quantifying the information obtainable via remote sensing, overall studies are needed to address an operational system. Operational system studies must consider the data volumes, the computational times required, the logistics of gathering, processing, and disseminating the data, and the cost of implementation. In FY-77, the Marshall Space Flight Center Data Management Program activities centered around the analyses of the far term (1985 and beyond) Office of Application objective of applying space technology to an operational Global Crop Production Forecasting System. The Global Crop Production Forecasting Trade Study (8) performed as part of this program identified major areas of disparity between projected technology and requirements. Out of this study, the concept of obtaining a repeated number of observations of sample regions via satellite was developed. The concept of reducing the data volume at the earliest point in the system was also advocated. From the previous studies, it is evident that remotely sensed multispectral image data will be a valuable and essential part of an operational agricultural system. However, there is no clearly decisive set of requirements currently established. Other studies such as Temporal Investigation for Mission Evaluation (TIME) (9) are directed toward further defining the requirements as a function of the agricultural science. This study is directed toward establishing the data system relationship between

*The ERTS was later renamed Landsat.

the requirements and methods of implementation. Several questions concerning the economic trade-offs for an operational system were singled out for further definition in this study. These questions are in two major areas. One is the number of satellites required to reliably obtain cloud free images at precise times during the growing season. The other is to better quantify the volume of data to be processed as a first step in optimizing a processing system. This report describes the investigation of these two factors.

STATEMENT OF THE PROBLEM

The goal of this study is to identify cost effective approaches to meeting the Global Crop Production Forecasting Objective. This implicitly favors approaches with a minimum number of satellites and a minimum amount of data processing requirements.

Satellites are major fixed cost elements in an operational system. As such, it is desirable to design a system that will use the minimum number of satellites and still perform satisfactorily. It is also desirable that the amount of data processing required be minimized. Because of the temporal nature of the information in a cropland image, the positioning of a satellite as a function of time is a principal requirement. The main driver that must be satisifed, which influences the minimum number of satellites to render satisfactory performance, is a function of this time dependent positional requirement and the number of picture elements needed to cover the world's agricultural areas. This number is a function of the spatial resolution required to obtain the desired accuracy. The image data acquired using satellites, as depicted in Figure 1, is processed and combined with other information called collateral data; 1) to measure or inventory the amount of land in production for particular crops, 2) to determine plant vigor as an indication of growth stage and potential yield, and 3) to assess the extent of stress from either environmental or induced episodes as it affects yield. Each of these uses of remotely sensed image information imposes constraints on the timing of data acquisition. Of the three, the inventory function is the best defined. Based on current United States crop production estimating practice, it is also the function most amenable to near term improvements from satellite sensed image data.

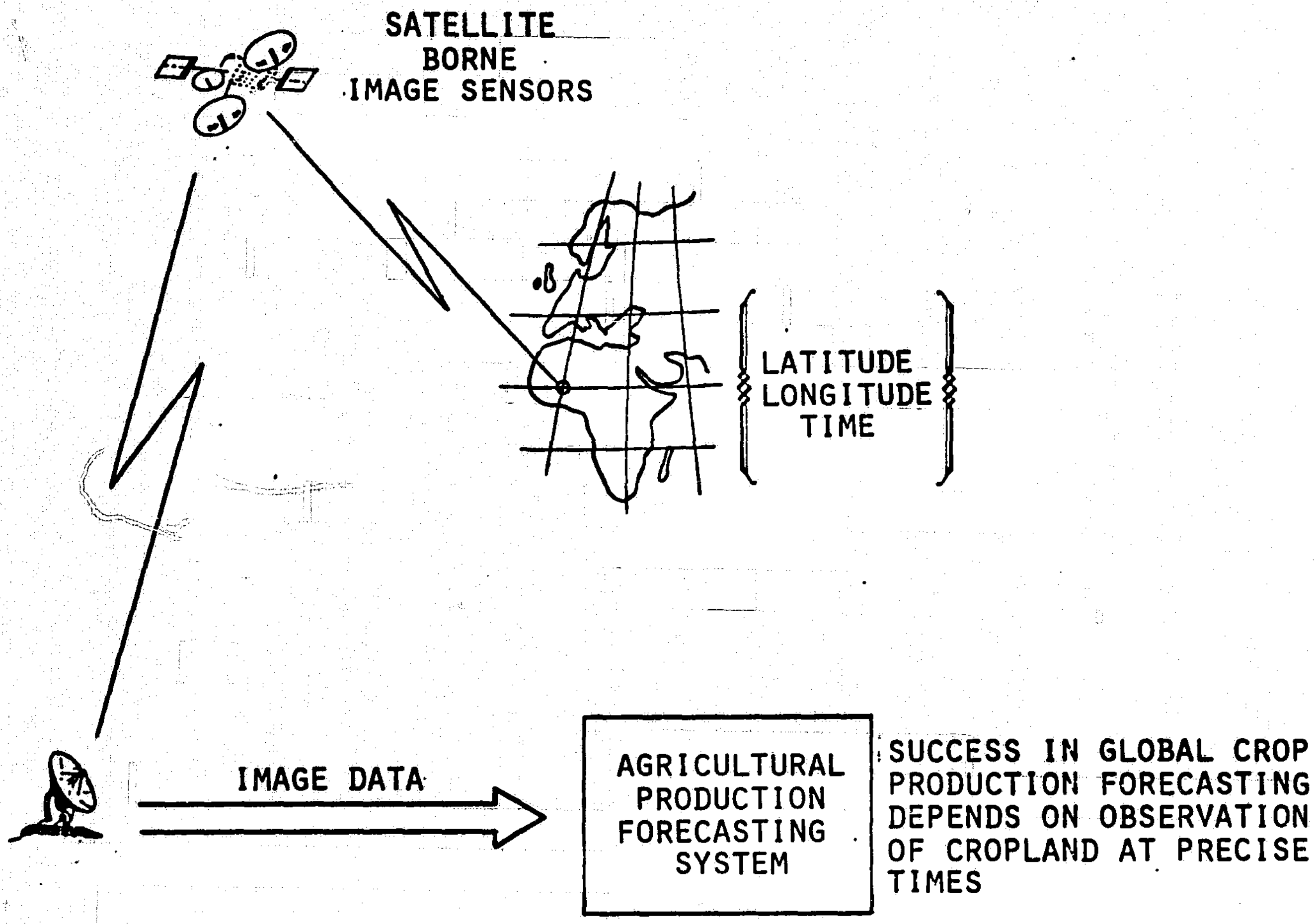


FIGURE 1. THE USE OF SATELLITES FOR AGRICULTURAL FORECASTING

This study is limited to accomplishing this inventory function only. It concentrates on determining the dependence of the success of obtaining the required information on orbital altitude, period, position, and sensor swath.

Other factors that indirectly impact the number of satellites needed and the data volumes encountered were considered. They form the baseline conditions for this study and are summarized in Table 1. The principal rationale for this baseline is that it is a reasonable set of conditions based on present technology and related studies. Any system expected to be operational in the 1985 time frame will be based on such current technology.

CONCLUSIONS

Results of this study support the following conclusions:

1. Use two satellites of the Landsat-D design to accomplish the agricultural inventory objective.
2. The nominal Landsat-D will perform satisfactorily.
3. Accept scenes with up to 90% cloud cover for preprocessing.
4. Use a regionally compensated oversampling strategy.
5. Extract samples immediately after preprocessing.

Additional results from this study indicate sufficient potential benefits to justify future study of the following alternatives:

1. Use a floating sample approach with a reduction in acceptable scene cloud cover to as little as 30%.
2. Use dedicated satellites with on-board sample extraction.
3. Increase the sensor swath width.

TABLE 1

TRADE STUDY BASELINE CONDITIONS

BASELINE	VALUE	RATIONALE
Spectral Bands	5 Visible + 1 IR	Existing Thematic Mapper Design
Spectral Resolution	128 Levels	Existing Thematic Mapper Design
Spatial Resolution	30 Meter Visible 120 Meter IR	Existing Thematic Mapper Design
Swath Width	100 NM	Existing Thematic Mapper Design
Crops	Wheat, Corn, Soybean, Rice	Trade Study 1 Results
Countries Regions	22 Major Ecological	Contribution to World Crop Value ECO Systems
Sun Synchronous Increased Swath	Yes Minimum Change	Analysis 1985 Operational Need
Low Altitude	Grazing Angle	1985 Operational Need, Landsat 1,2 Experience; BRP
Window Length	Discrimination	ECO Systems (Ref. 8)
Confidence Limits	1/20 Year	ECO Systems (Ref. 8)
Sample Segment Size	1 KM	Discrimination & Confidence ECO System (Ref. 8)
No. of Samples	1000 Base	ECO Systems (Ref. 8)
Use of Samples Cloud Condition	Yes	Trade Study 1 (Ref. 10) Allied Cloud Model

STUDY APPROACH

The approach used for this investigation was to model the satellites, their movement and observation capability, world cloud conditions, and major growing regions for wheat, corn, soybeans, and rice using the general simulation capability of MSFC's Data System Dynamic Simulator (DSDS)(11). Twenty-two countries were chosen based on the criteria that each contributed two percent or more to the world harvest of one of the selected crops. The larger countries were divided into geographic regions corresponding to statistical reporting districts. The point target capability of DSDS was used to provide a statistically sound measure of variations due to geographic location and cloud conditions. A minimum number of samples in a simulation region was set at 30 for a geographic region containing only one crop. The number of samples was adjusted to a maximum of 60 when all four crops were grown in a region.

This approach resulted in 1553 samples for the world (see Table 2) and permitted the collection of statistics on individual samples and regions. This permitted a measure of the effects of opportunity variations due to overlap in coverage, length of time during which observations could be obtained, and the effects of localized cloud conditions. The number of samples drawn for an operational system varies for each region according to local accuracy considerations and can be scaled from the simulation data. Table 2 lists each country, its regions and crops, the number of samples used in the simulation model and the number of samples estimated to be needed for an operational system.

Alternatives to optimizing the number of satellites were considered. A working Blue Ribbon Panel*, made up of technical people working in related disciplines, considered the technical feasibility, the practicality, the cost impact and any additional constraints likely to be encountered for each alternative. Those alternatives appearing most likely to be successful were conceptualized as candidate systems. The Data Systems Dynamic Simulator was used to measure parametric variations in the candidate systems.

*This panel consisted of General Electric and NASA personnel and convened for the purpose of this Trade Study. The panel met in Beltsville, MD, Nov. 9, 1977. Individual panel members subsequently provided consultation for this study.

TABLE 2. COUNTRIES, REGIONS, CROPS, AND NUMBER OF SAMPLES USED FOR STUDY

Country & Region	Crops	Number of Simulation Samples	Estimate of # of Operational Sample Segments
Argentina	W,C	45	1500
Australia	W	30	1000
Bangladesh	R	30	1000
Brazil North	C	30	1000
Brazil South	C,S,R	53	1767
Canada	W	30	1000
China North	W,C,S,R	60	2000
China Central	W,C,S,R	60	2000
China South	W,C,S,R	60	2000
Egypt	C	30	1000
France	W,C	45	1500
India Punjab	W,C	45	1500
India Ganges	W,C,R	53	1767
India Central	W,C,R	53	1767
India Bilaspur	W,C,R	53	1767
India Coastal	R	30	1000
Indonesia	R	30	1000
Italy	W,C,R	53	1767
Japan	R	30	1000
Mexico	C	30	1000
Pakistan	W	30	1000
Romania	W,C	45	1500
South Africa	C	30	1000
Philippines	R	30	1000
Thailand	R	30	1000
Turkey	W	30	1000
USA - Region A	W,C,S	53	1500
USA - Region B	W,C	45	2000
USA - Region C	W,C,S,R	60	2000
USA - Region D	W,C,S,R	60	2000
USSR Latvia	W,C	45	1500
USSR Ukraine	W,C	45	1500
USSR Transvolga	W,C	45	1500
USSR Volga-Ural	W,C	45	1500
USSR Siberia	W,C	45	1500
Yugoslavia	W,C	45	1500
TOTAL		1553	51355

W = Wheat, C = Corn, S = Soybeans, R = Rice

ALTERNATIVES INVESTIGATED

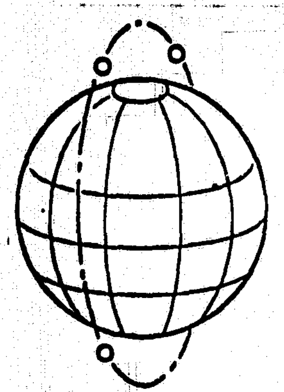
Some alternatives for optimizing the number of satellites were investigated and a brief disposition of each is included in Appendix A. Four candidate systems were chosen for further exploration using DSDS. They all have the property of using the currently designed Landsat-D vehicle, in some cases with modification to the sensor system or operational procedures. The four systems with their characterizing features are illustrated in Figure 2. Except for System 2, the orbital altitudes are sufficiently close to the nominal 704 KM design altitude of the Thematic Mapper scheduled for use on Landsat-D that a sensor and satellite redesign will not be required. As King(12) described, an operational system could use different altitudes and satellite positions at different times according to needs with a small impact on the consumable budget. The four candidate systems comprise combinations of satellites in four different sun-synchronous orbits. Each of these orbits were investigated using DSDS.

704 KM ORBIT - NOMINAL LANDSAT-D

A sun-synchronous orbit at an altitude of 704.052 KM and an inclination of 98.204 degrees provides total earth coverage every 16 days. This is the design orbit of the Landsat-D with the Thematic Mapper covering 185 KM swath on each orbit. Every 233 orbits, the nadir repeats itself.

It has the advantage of not requiring special programming of its position as well as providing complete global coverage. It is inefficient from an agricultural viewpoint because it is often over uninteresting regions such as oceans or deserts. The time between repeat coverage of 16 days is unacceptable at certain times either because of the temporal nature of the information or because of delay in acquiring information unobtained due to atmospheric conditions. To overcome these difficulties, additional satellites may be used. One outcome of the study was a measure of the effectiveness of additional satellites at this orbit versus other orbits for obtaining the desired samples.

CANDIDATE SYSTEM 1



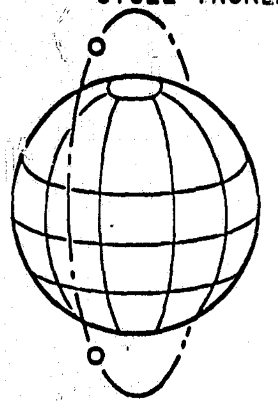
185 KM SWATH - 704 KM ALT.

NO. OF SATELLITES	TOTAL WORLD COVERAGE CYCLE
1	16 DAYS
2	8 DAYS
3	5 1/3 DAYS

LANDSAT-D SATELLITE

CANDIDATE SYSTEM 2

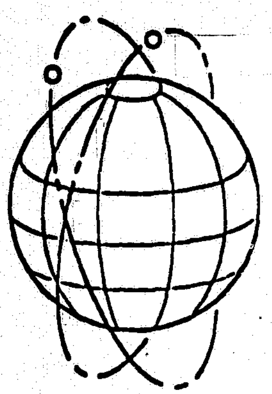
TWO SATELLITES 1485 KM EACH 20 DAY REPEAT CYCLE INCREASED SWATH



TOTAL WORLD COVERAGE EVERY 10 DAYS (OR LESS) AS FUNCTION OF SWATH.

MODIFIED LANDSAT-D SATELLITE

CANDIDATE SYSTEM 3

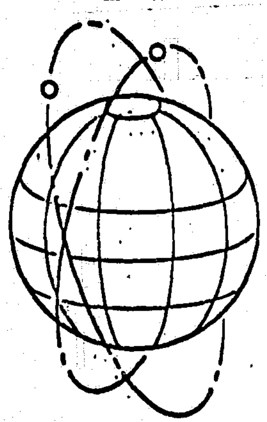


ONE SATELLITE AT 704 KM
(16 DAY REPEAT)

ONE SATELLITE AT 743 KM
(9 DAY REPEAT)

LANDSAT-D SATELLITE

CANDIDATE SYSTEM 4



ONE SATELLITE 704KM
(16 DAY)

ONE SATELLITE AT 725 KM
(2 DAY)
(PROGRAMMABLE POINTED)

LANDSAT-D SATELLITE

GROUND SCHEDULING SYSTEM

FIGURE 2. FOUR CANDIDATE AGRICULTURAL DATA COLLECTION SYSTEMS

743 KM ORBIT

An increase of 39 KM in altitude provides an orbit that repeats after 130 orbits. This is insufficient to provide total earth coverage with 185 KM swath. It covers only 24,050 KM or about 60 percent of the area at the equator. It does offer the advantage of 9-day repetition, which when combined with other orbits has the potential to provide optimum coverage of areas of agricultural interest. Additional capability of an orbit that repeats frequently can be obtained using the stabilization system in the Landsat-D which can be biased to provide some off nadir pointing. One swath width is the usually accepted limit. Because of these possibilities, this orbit of 742.57 KM and a sun-synchronous inclination of 98.367 degrees was investigated.

725 KM ORBIT

A potentially useful orbit between the 704 KM 16-day repeat and the 743 KM 9-day repeat occurs at 724.35 KM. It repeats itself every 29 orbits or two days. While it only covers about 1/8 of the world at the equator, it has the advantage of a short repeat cycle. When combined with satellites at other orbits, and use is made of one swath pointing as well as position adjustments, areas of specific interest could be frequently observed. Such a system assumes the dedication of the satellite to the needs of the agricultural user so it can be pointed or positioned without concern for loss of data to other users. The sun-synchronous inclination for this orbit is 98.292 degrees.

1485 KM ORBIT

One additional orbit was investigated at 1484.65 KM, with a sun-synchronous inclination of 101.874 degrees. This altitude, being about twice the normal Landsat-D orbit, would require a redesign of the Thematic Mapper.

While repeating at a longer period, every 20 days, it might permit greater flexibility of pointing without encountering unacceptable radiometric and geometric difficulties due to the grazing angle with the earth. This grazing angle is discussed in Appendix B.

INVESTIGATION PROCESS

The Data System Dynamic Simulator (DSDS) at MSFC was used to determine the following:

- o Orbital position of the satellites as a function of time and orbital parameters.
- o The sensor field of view as a function of satellite position and swath width.
- o The state of the samples within the field of view as a function of the cloud model.
- o The statistics on the target acquistions as a function of the above, the preprocessing acceptance criteria and the processing requirements.

The DSDS combined the dynamics of satellite position, crop models, cloud models, and processing requirements. A Monte-Carlo method was used in conjunction with a cloud model to inject the realism of cloud cover into the simulation.

The simulation was segmented as illustrated in Figure 3. For economy of simulation time, the results of each successive simulation segment were saved and used for later parametric variations. For example, for a one year simulation of satellite positions repeating every 16 days, the mission ephemeris was generated for 16 days and reused. For different sensor swath widths for the same satellite positions, the same mission model data was used. The results of the Mission Model, sensor swath, and target described the data available from one satellite. Any combination of satellites desired were combined in the multivehicle crop model to constitute one of the candidate systems. Thus, such subtle effects as the difference in insertion time and position offset for a 3 Landsat vehicle system were included. The effect of

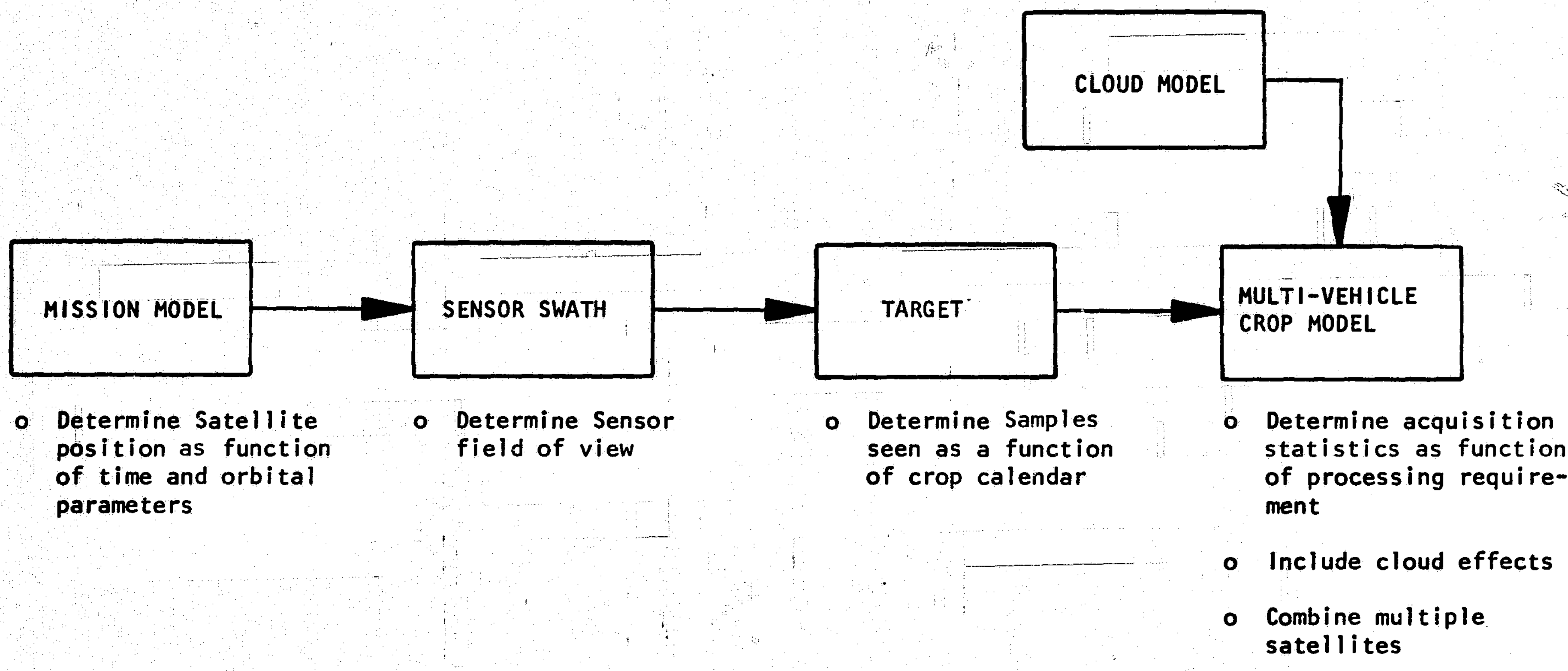


FIGURE 3. DSDS MODEL

cloud conditions were determined by a comparison of a random number against the predesignated cloud condition breakpoints for the cloud region corresponding to each sample. The acceptable cloud conditions for preprocessing was the first criterion to be met for all the samples in a scene 90 nautical miles along track and one swath width wide. A subsequent random number was compared with the scene cloud conditions to determine if each sample was clear or cloudy. A more detailed discussion of the DSDS models and the available data is presented in Appendix C.

PERFORMANCE OF CANDIDATE SYSTEM 1 WITH 1, 2, OR 3 SATELLITES

A major portion of this study consisted of establishing the capability of obtaining cloud free observations of the desired sample segments* with nominal Landsat-D satellites.

The bar chart in Figure 4 gives a rapid comparison of the results achieved with 1, 2, and 3 satellites. Each bar in Figure 4 represents the mean percent of samples acquired at the 50% confidence level for each of the 36 regions. The last bar for each of the 3 cases is the world average. The data is taken from columns 1, 5, and 9 of Table 3. Additional information from Figure 4 is summarized below.

Number of Satellites	Mean Percent of Desired Obs. Achieved	Percent of Regions Obtaining 98% of Needed Samples	Minimum Percent Achieved for Any Region
1	87.1	16.6	72.3
2	97.0	69.4	91.6
3	99.2	88.8	96.3

The mean and standard deviation for the percent of samples for which cloud free observations were missed are presented in Table 4. The two satellite data is based on 20 simulation runs and the three satellite data is based on 7 runs. The 50% and 95% confidence limits for obtaining samples were determined for this data. The 95% confidence level corresponds to cloud free

*As a vehicle of distinction, the term sample segment will be used when referring to the image data 1 KM x 1 KM in the modeled operational system and the word sample will be used when referring to the point representation in the simulation.

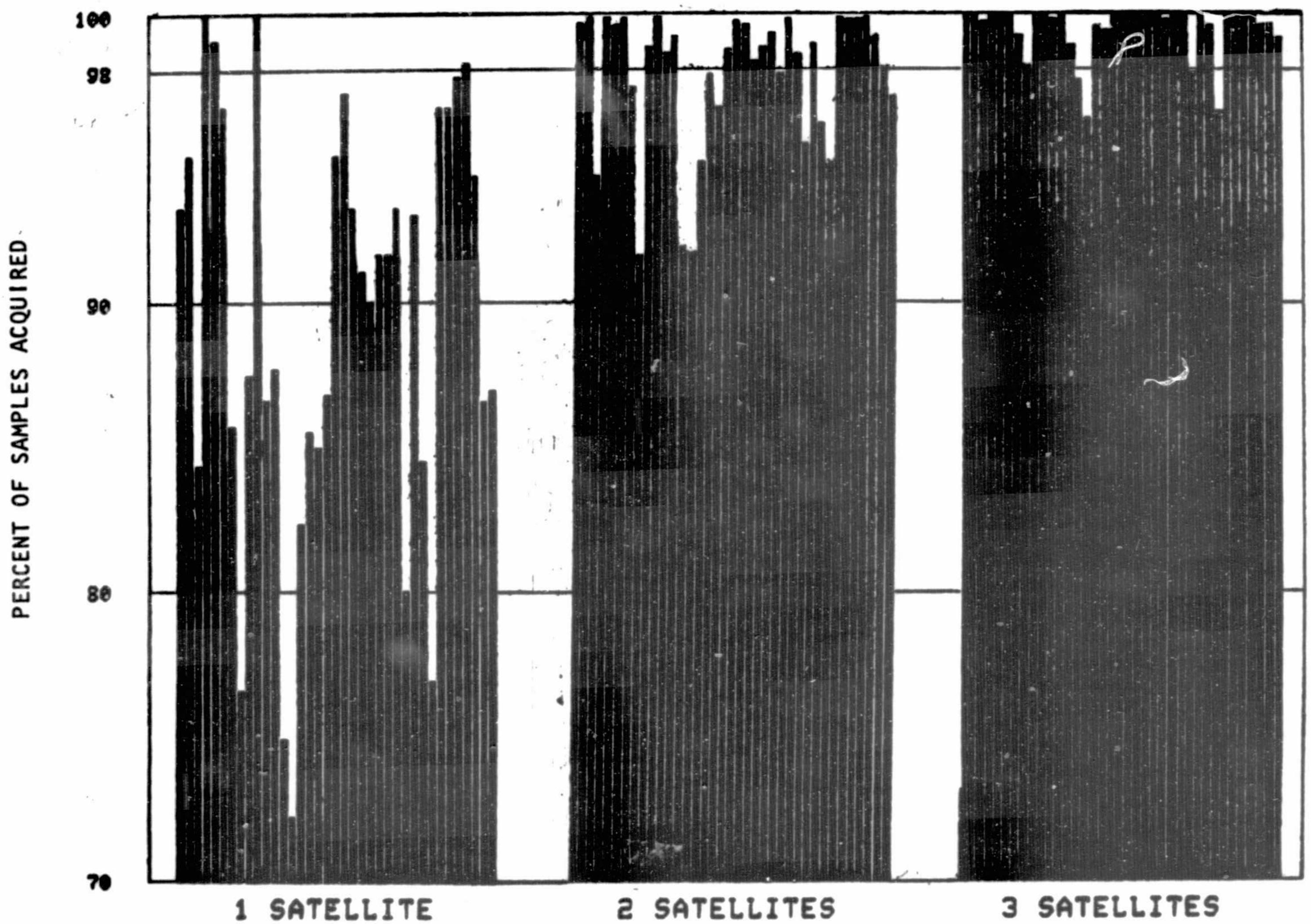


FIGURE 4. COMPARISON OF 1, 2, AND 3 LANDSAT-D SATELLITES

Note: Each bar represents a region.

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TABLE 3. PERCENT OF SAMPLES ACQUIRED FOR EACH TEST CASE

COLUMN NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NUMBER OF VEHICLES	1	1	1	1	2	2	2	2	3	1	1	2	2	2
VEHICLE ALTITUDE	704	704	704	704	704	704	704	704	704	1485	1485	1485	704 & 725	704 & 743
SWATH WIDTH (KM)	185	185	222	222	185	185	222	222	185	185	222	185	185	185
MAXIMUM CLOUD COVER ACCEPTED (%)	50	90	50	90	50	90	50	90	50	50	50	50	50	50
NO. OF RUNS AVERAGED	7	1	1	1	20	1	1	1	7	2	2	1	1	1
WORLD AVERAGE	87.11	92.14	92.31	94.91	96.99	98.84	97.88	99.38	99.18	83.12	88.88	96.51	87.97	96.65
ARGENTINA	93.3	97.8	98.9	98.9	99.6	100.0	100.0	100.0	100.0	92.8	96.1	100.0	100.0	100.0
AUSTRALIA	95.0	100.0	98.3	90.0	99.8	100.0	100.0	100.0	100.0	91.7	100.0	100.0	100.0	100.0
BANGLADESH	84.4	95.6	93.9	96.7	94.3	100.0	94.4	98.9	99.7	82.8	85.6	97.8	80.0	96.7
BRAZIL - NORTH	100.0	96.7	96.7	100.0	99.9	100.0	100.0	100.0	100.0	90.0	95.0	100.0	96.7	100.0
BRAZIL - SOUTH	99.1	98.1	100.0	98.1	99.5	100.0	100.0	100.0	100.0	92.5	92.5	100.0	96.2	98.1
CANADA	96.7	96.7	100.0	100.0	99.8	100.0	100.0	100.0	100.0	96.7	100.0	100.0	96.7	100.0
CHINA - NORTH	85.8	88.3	91.2	96.7	97.4	100.0	100.0	100.0	99.2	85.8	90.0	97.5	84.2	96.7
CHINA - CENTRAL	76.7	90.8	78.3	83.3	91.6	92.5	96.7	97.5	98.1	71.2	79.2	89.2	85.8	94.2
CHINA - SOUTH	87.5	90.0	90.0	96.7	98.8	98.3	100.0	100.0	100.0	91.7	88.3	98.3	86.7	98.3
EGYPT	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.3	98.3	100.0	100.0	100.0
FRANCE	86.7	97.8	92.8	95.6	98.5	100.0	100.0	100.0	99.8	86.7	92.8	96.7	92.2	100.0
INDIA - PUNJAB	87.8	98.9	96.7	98.9	99.2	100.0	100.0	98.9	100.0	91.7	92.2	100.0	95.6	98.9
INDIA - GANGES	75.0	85.4	95.8	98.1	91.9	98.1	86.8	98.1	98.1	63.0	76 9	91.0	58.0	96.7
INDIA - CENTRAL	72.3	90.6	85.8	94.3	91.7	95.6	96.2	97.5	97.6	71.1	76.7	96.9	67.9	95.0
INDIA - BILASPUR	82.4	89.9	84.3	88.7	94.8	97.5	95.6	100.0	96.3	66.4	81.4	91.8	78.0	88.7
INDIA - COASTAL	85.6	87.8	92.2	91.1	97.8	100.0	97.8	100.0	99.5	88.3	89.4	98.9	91.1	95.6
INDONESIA	85.0	91.1	83.3	88.9	96.6	100.0	96.7	98.9	99.4	75.6	80.0	94.4	76.7	87.8
ITALY	86.9	93.5	94.9	94.4	98.7	100.0	100.0	100.0	99.9	88.3	93.5	98.1	96.3	100.0
JAPAN	95.0	93.3	98.3	96.7	99.7	100.0	100.0	100.0	100.0	91.7	98.3	100.0	90.0	100.0
MEXICO	97.2	98.9	95.6	95.6	99.6	100.0	100.0	100.0	100.0	92.2	96.7	92.2	100.0	100.0
PAKISTAN	93.3	80.0	98.3	100.0	98.3	100.0	100.0	100.0	100.0	91.7	91.7	100.0	93.3	96.7
ROMANIA	91.1	91.1	88.9	94.4	98.8	100.0	100.0	100.0	100.0	86.1	96.1	98.9	97.8	94.2
S. AFRICA	90.0	93.3	88.3	93.3	99.3	100.0	100.0	100.0	100.0	90.0	90.0	100.0	100.0	100.0
PHILIPPINES	91.7	96.7	91.7	91.7	97.8	100.0	96.7	98.3	99.8	83.3	94.2	98.3	95.0	90.0
THAILAND	91.7	96.7	96.7	100.0	99.8	100.0	100.0	100.0	100.0	93.3	88.3	96.7	86.7	96.7
TURKEY	93.3	80.0	91.7	96.7	98.5	100.0	100.0	100.0	100.0	78.3	91.7	100.0	86.7	96.7
US - A	80.0	80.0	80.4	90.4	95.4	98.3	98.3	99.1	97.9	73.5	84.8	93.9	89.6	96.5
US - B	93.0	93.0	97.2	98.6	98.9	100.0	100.0	100.0	100.0	88.7	93.7	98.6	91.5	100.0
US - C	84.6	87.9	95.3	97.2	96.1	97.2	97.2	100.0	99.6	85.5	84.6	93.5	89.7	98.1
US - D	77.0	84.7	86.7	85.7	94.8	96.9	96.9	98.0	96.5	74.0	83.2	93.9	85.7	90.8
USSR - LATVIA	96.7	100.0	97.8	98.9	99.9	100.0	100.0	100.0	100.0	97.8	97.8	100.0	96.7	100.0
USSR - UKRAINE	96.7	96.7	100.0	100.0	99.8	100.0	100.0	100.0	100.0	97.8	98.9	100.0	100.0	98.9
USSR - TRANS-VOLGA	97.8	95.6	97.2	100.0	99.8	100.0	100.0	100.0	100.0	97.8	98.9	100.0	98.9	100.0
USSR - VOLGA-URAL	98.3	96.7	98.3	98.9	99.9	100.0	100.0	100.0	100.0	93.3	96.7	100.0	94.4	100.0
USSR - SIBERIA	94.4	97.8	93.3	100.0	99.2	97.8	100.0	100.0	99.7	86.7	91.1	100.0	97.8	97.8
YUGOSLAVIA	86.7	95.6	97.2	97.8	98.0	100.0	100.0	100.0	99.7	79.4	90.6	95.6	92.2	100.0

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TABLE 4. MEAN AND STANDARD DEVIATION FOR THE PERCENT OF SAMPLES MISSED *

COUNTRY/REGION	2 LANDSAT-D VEHICLES MEAN	2 LANDSAT-D VEHICLES STD. DEV.	3 LANDSAT-D VEHICLES MEAN	3 LANDSAT-D VEHICLES STD. DEV.
EGYPT	0	0	0	0
AUSTRALIA	0.17	0.74	0	0
CANADA	0.17	0.74	0	0
THAILAND	0.17	0.74	0	0
USSR - LATVIA	0.06	0.25	0	0
USSR- VOLTA-URAL	0.06	0.25	0	0
USSR - UKRAINE	0.17	0.41	0	0
USSR - TRANS-VOLGA	0.17	0.54	0	0
USSR - SIBERIA	0.78	1.30	.32	.84
BRAZIL - SOUTH	0.09	0.42	0	0
BRAZIL - NORTH	0.50	1.22	0	0
JAPAN	0.33	1.02	0	0
ARGENTINA	0.44	0.66	0	0
MEXICO	0.44	0.66	0	0
S. AFRICA	0.67	1.74	0	0
ROMANIA	1.17	1.22	0	0
ITALY	1.26	1.10	.13	.35
FRANCE	1.50	1.41	.16	.42
TURKEY	1.50	2.29	0	0
PAKISTAN	1.67	2.54	0	0
YUGOSLAVIA	2.00	2.06	.32	.54
PHILIPPINES	2.25	2.61	.64	.87
INDONESIA	3.44	2.52	.64	.87
USA - REGION B	1.13	1.18	0	0
USA - REGION C	3.88	1.15	.40	.50
USA - REGION A	4.65	2.26	2.11	.99
USA - REGION D	5.15	2.26	3.50	1.16
CHINA - SOUTH	1.25	1.70	0	0
CHINA - NORTH	2.64	3.57	.83	.83
CHINA - CENTRAL	8.42	2.27	1.90	1.15
BANGLADESH	5.66	5.72	.32	.54
INDIA - PUNJAB	0.78	1.57	0	0
INDIA - COASTAL	2.16	1.51	.48	.59
INDIA - BILASPUR	5.19	3.67	3.69	3.77
INDIA - GANGES	8.07	6.61	1.14	.81
INDIA - CENTRAL	8.30	4.40	2.43	1.97
WORLD	3.01	0.50	.82	.30

*Failure to obtain 1 cloud free observation during the designated time for each sample segment constitutes a miss.

observation in 19 out of 20 years. The cloud free samples required for the 36 regions are shown in Figures 5 and 6. Solid bars represent 95% confidence level and the crosshatched bars represent 50% confidence level. On Figure 5 (two satellite case), it can be seen that only 5 of the 36 regions will furnish less than 90% of the sample segments. On Figure 6, it can be seen that with three satellites, none of the 36 regions will have less than 90% of the sample segment needed. These results are based on only using scenes with 50% cloud cover or less.

COMPARISON OF CANDIDATE SYSTEMS

The candidate systems were compared based on their capability of obtaining 98% of the designated samples in each region. Each candidate system is described in Figure 2.

The percent of samples acquired regionally for each test case is presented in Table 3. Test cases 1 through 9 apply to candidate system 1; Test cases 10, 11, and 12 apply to candidate system 2; and Test cases 14 and 13 apply to candidate systems 3 and 4, respectively. A summary of this data is shown in Figure 7.

Of the four two-satellite candidate systems, the 704 KM orbit or nominal Landsat-D performed the best. The combination of one vehicle at 704 KM and one at 743 KM, system 3, performed nearly as well and has the advantage of providing additional viewing opportunities when repeat coverage is required. System 2, with two vehicles at 1485 KM, performed approximately the same as System 3. A disadvantage of System 2 is that a redesign of the sensor would be required because of the substantial increase in altitude from the nominal Landsat-D. System 4 performed poorer than any of the other candidates. This is because the two-day repeat satellite at 725 KM only has an opportunity to view 20.3% of the needed samples.

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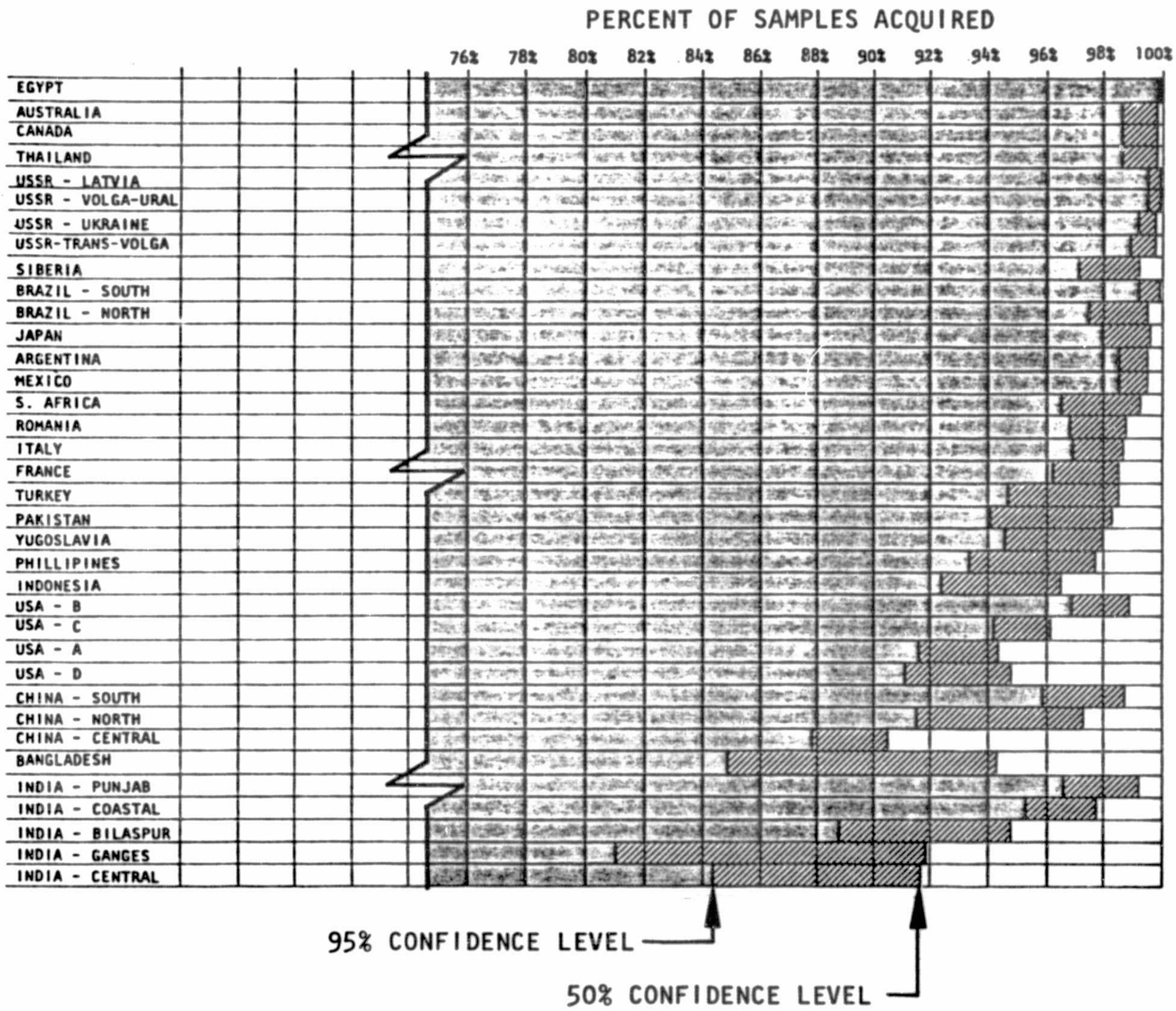
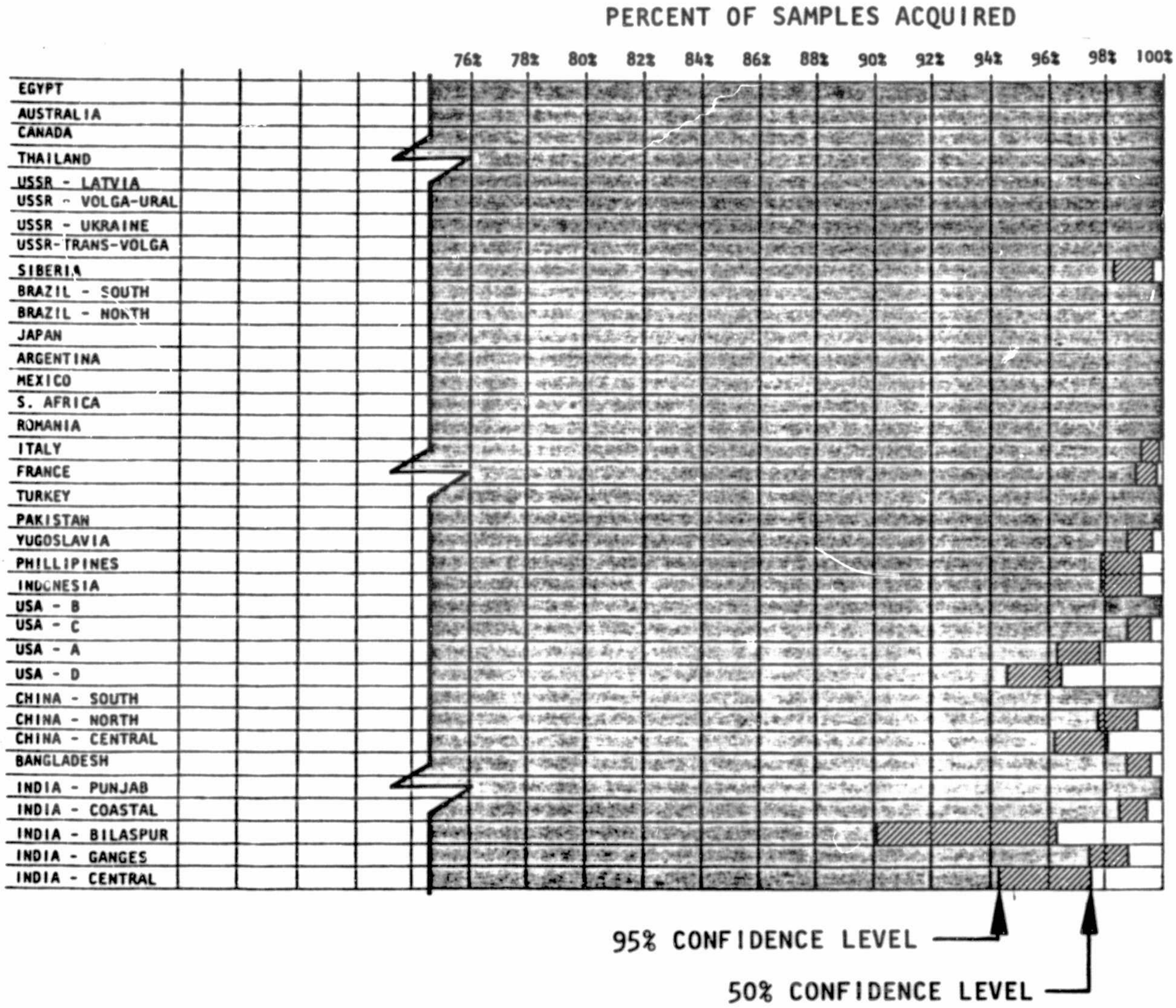


185 KM SWATH - 50% CC ACCEPTED

FIGURE 5. PERCENT OF SAMPLES ACQUIRED WITH 2 LANDSAT SATELLITES



185 KM SWATH - 50% CC ACCEPTED

FIGURE 6. PERCENT OF SAMPLES ACQUIRED WITH 3 LANDSAT SATELLITES

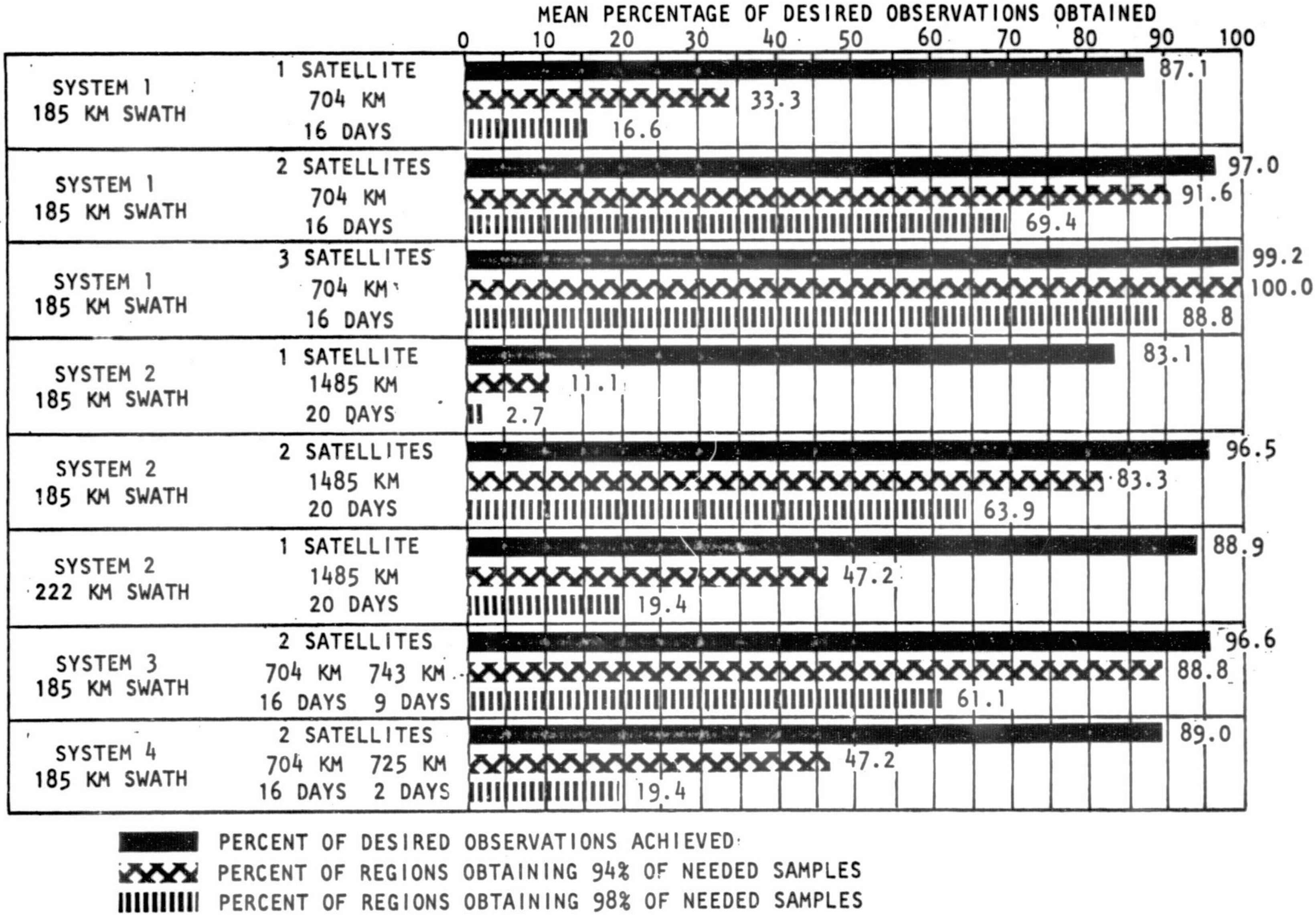


FIGURE 7. COMPARISON OF SYSTEMS ON WORLD WIDE SAMPLE ACQUISITION

EFFECT OF INCREASED SWATH WIDTH

Comparison runs for a 20 percent increase in swath width were made for candidate systems 1 and 2. The percent of samples acquired, the increase in samples acquired due to increased swath width, and the reduction in the number of samples missed for each case are tabulated below:

TABLE 5. EFFECT OF 20% INCREASED SWATH WIDTH

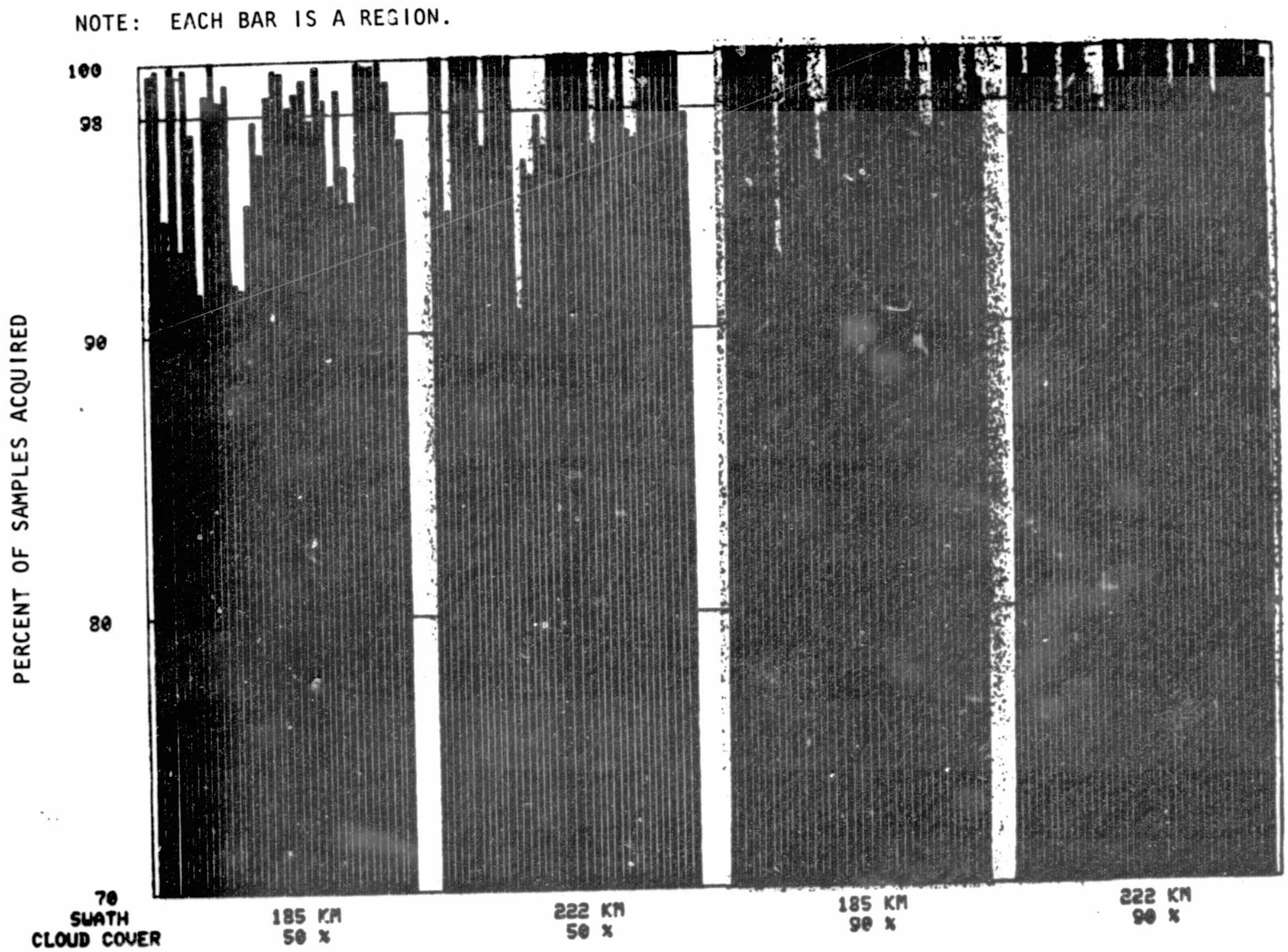
Number of Satellites	Altitude KM	Samples Acquired Percent 185 KM Swath	Samples Acquired Percent 222 KM Swath	Samples Acquired % Increase	Samples Missed % Reduction
1	704	87.1	92.3	6.0	40.3
2	704	97.0	97.9	0.9	30.0
1	1485	83.1	88.9	7.0	34.3
2	1485	96.5	97.8	1.3	37.1

As can be seen, a 20 percent increase in swath width causes a maximum of 7.0 percent increase in the samples acquired. However, there is a reduction in the percent of samples missed of 30.0 to 40.3 percent. Thus, a small percentage increase in swath width yields approximately a 2 to 1 percentage reduction in the number of samples missed.

The effect of increased swath width is shown in Figure 8 for one Landsat Satellite and in Figure 9 for two satellites. In both figures, the percent of samples acquired in each of the 36 regions is shown for four cases. Starting on the left side of the figure, the four cases are:

- o Nominal Landsat-D
- o 20 % cloud cover accepted
- o 90% cloud cover accepted
- o Increased swath width and clouds

Figures 8 and 9 give a quick appreciation for the benefits of increased cloud cover acceptance and swath width. Two satellites with increased swath and cloud cover acceptance perform slightly better than the nominal three satellite case.



CONDITION	NOMINAL	INCREASED SWATH	INCREASED CLOUDS	INCREASED SWATH AND CLOUDS
OVERALL % SAMPLES ACQUIRED	87.11	92.31	92.14	94.91

FIGURE 8. EFFECT OF INCREASED SWATH AND HIGHER CLOUD COVER ACCEPTANCE FOR ONE LANDSAT-D SATELLITE

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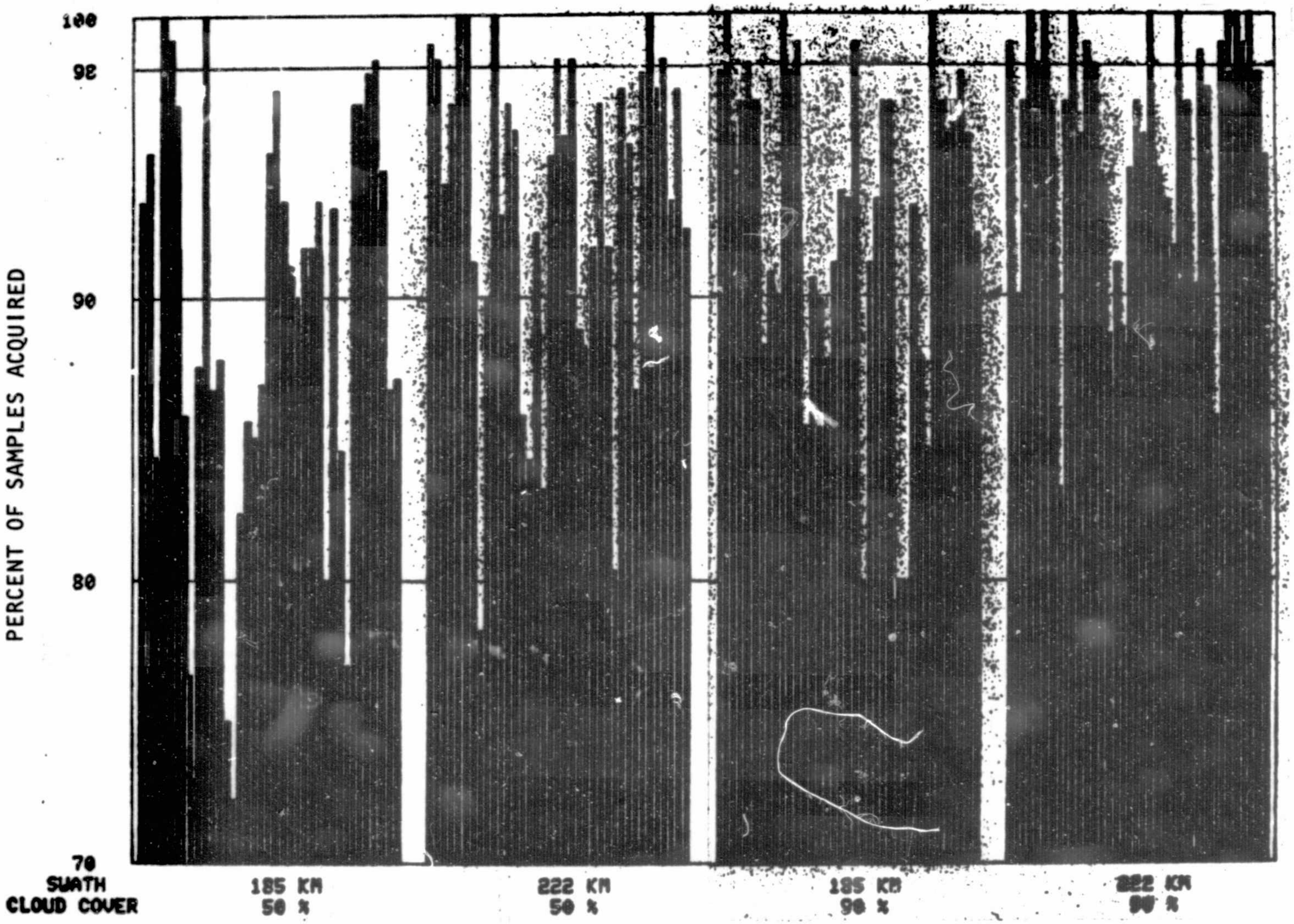
NOTE: EACH BAR IS A REGION.



CONDITION	NOMINAL	20% INCREASED SWATH	INCREASED CLOUDS	INCREASED SWATH AND CLOUDS
OVERALL % SAMPLES ACQUIRED	96.99	97.88	98.84	99.38

FIGURE 9. EFFECT OF INCREASED SWATH AND HIGHER CLOUD COVER ACCEPTANCE FOR TWO LANDSAT-D SATELLITES

EFFECT OF INCREASED CLOUD COVER ACCEPTANCE

The effect of accepting scenes with up to 90% cloud cover upon the ability to obtain needed samples was investigated for one and two Landsat-D satellites. The results from the four cases compared are shown below:

Number of Satellites	Maximum Cloud Cover Accepted (Percent)	Samples Acquired (Percent)	Samples Acquired % Increase	Samples Missed % Reduction
1	50	87.11	-	-
1	90	92.14	5.8	39.0
2	50	96.99	-	-
2	90	98.84	1.9	61.5

Increasing the acceptable cloud cover at the preprocessor had a significant effect on reducing the percent of samples missed for the two satellite cases. On a global basis, it reduced the percent of samples missed by 61.5%. For the five regions in Figure 5 which did not achieve 90% of the needed samples at the 95% confidence level, the mean percent of samples acquired increased from 92.86% to 96.74%. Thus, through regionally selected use of scenes with up to 90% cloud cover and a small percentage of oversampling (up to 10%), the 98% of samples needed for each region would be obtainable.

The effect of increased cloud cover on the processing load is shown below:

Cloud Category Accepted	Maximum Cloud Cover Accepted (Percent)	Samples Acquired (Percent)	NUMBER OF SCENES TO BE PROCESSED: Total For Year	Peak Day	Average for Peak Period
2	30	94.09	4790	47	36 (26)
3	50	96.99	6383	59	48 (34)
4	90	98.84	9317	85	70 (50)

5 Day Work Week

(7 Day Work Week)

The average number of scenes to be processed per day during the peak growing season from May to September is based on processing only one observation per window. This was chosen to measure the sensitivity of obtaining samples versus the number of satellites. The actual number of observations required is expected to be greater, but the exact number has not been determined.

From Figure 5, it can be seen that in order to obtain 98% of needed samples, scenes with up to 90% cloud cover would be required in 25 of the 36 regions if minimum oversampling is used. If oversampling is used to obtain all additional samples in regions where at least 92% of the samples are obtained, then scenes with up to 90% cloud cover would only be required in 9 of the 36 regions. Thus, depending upon the amount of oversampling used, the average processing load to obtain one observation per window during the peak period will fall somewhere between 48 and 70 scenes per day.

EFFECT OF WINDOW LENGTH

The primary factor effecting a given system's capability of obtaining needed sample segments is the observation period or window length. In this study, window lengths were set to maximize the probability of discriminating each crop from the other major crops and confusion crops in a given phenological region. Window lengths varied from 18 to 76 days (1 1/8 to 4 3/4 repeat cycles).

The samples in the United States were divided into four sets based on window length. The mean and standard deviation of the samples for which clear observations were missed are listed below as a function of window length. This data is based on a 20 year simulation for a system with two Landsat-D satellites.

Set	Range of Window Length (Days)	Average Window Length (Days)	Samples Missed (Percent) Mean	Samples Missed (Percent) Standard Deviation
1	18	18.0	12.75	4.14
2	28	28.0	4.75	1.78
3	32-47	41.7	0.61	0.70
4	65-76	68.0	0.06	0.26

The 50% and 95% confidence limits for the samples acquired as a function of window length are plotted in Figure 10. A window length of 40 days is required to obtain 98% of the needed targets at a 95% confidence level.

The three Landsat-D satellite system was run with fixed window lengths of 15, 20, 25, and 30 days. The results plotted in Figure 11 are for the U.S. alone and for the average of all regions. Samples missed in the U.S. was below 2% for a 24-day window and below 2% for the world for a 28-day window.

RELATIVE OBSERVATION PERIOD

In addition to window length, the overlap between adjacent swaths affects a system's capability of obtaining clear observations. For each region, Table 6 lists the mean window length, the mean latitude, overlap, relative observation period and percent of targets missed. The relative observation period is calculated as: Relative Observation Period = Window Length X (1 + Overlap). The percent of targets missed in each region is plotted in Figure 12 as a function of the relative observation period. A curve, drawn through the points, crosses the 2% line with a relative observation period of 56 days. The large spread about the curve is due to differing cloud conditions for regions with the same relative observation period.

MULTIPLE OBSERVATION PERFORMANCE

To determine the capability of obtaining more than one observation during a window, the number of observations accepted for processing was varied from 1 to 6 per sample.

Figure 13 shows the capability of obtaining multiple clear observations from one satellite for each of the four orbits investigated. This shows the advantage of 725 KM orbit if frequent coverage of a limited area is required

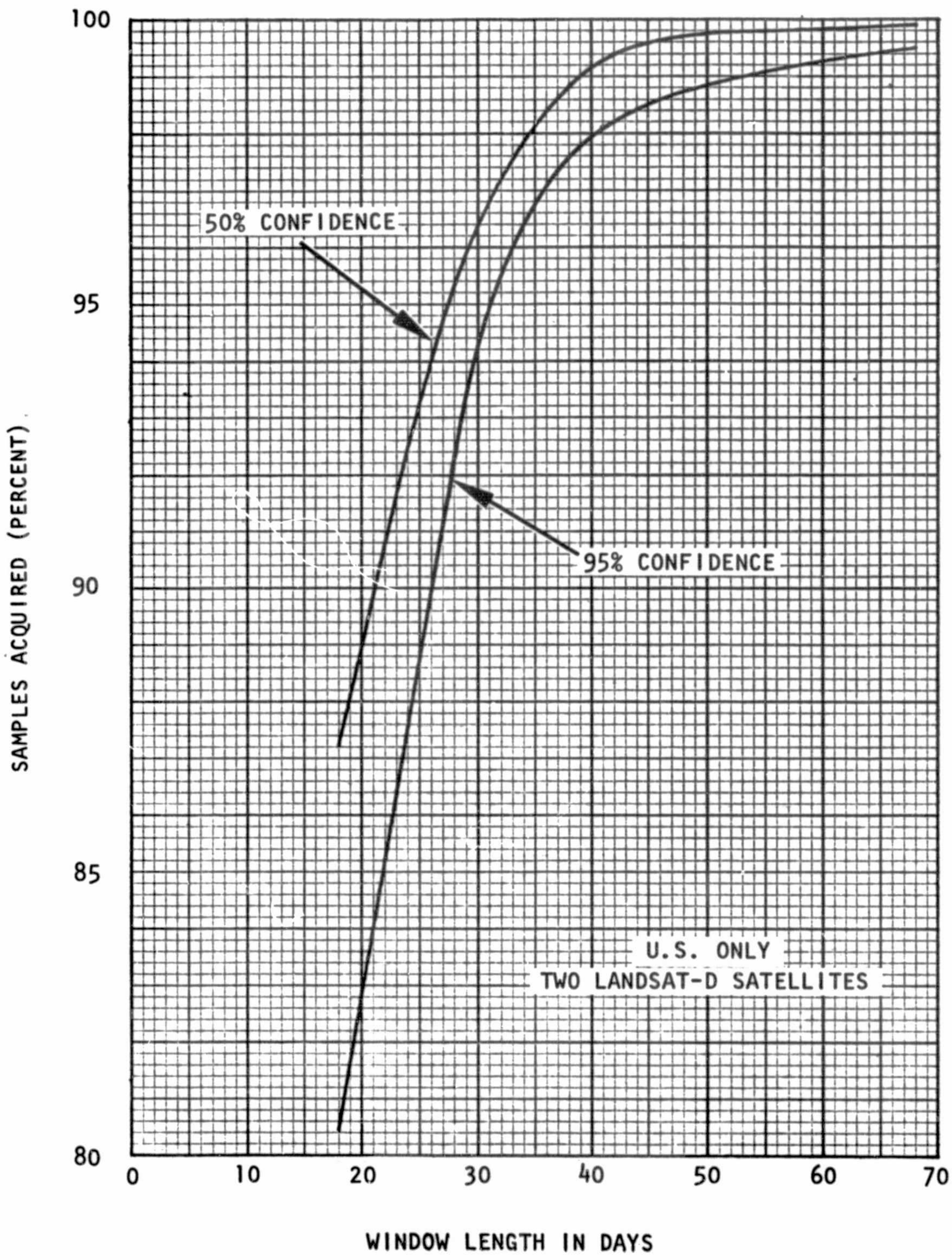


FIGURE 10. SAMPLES ACQUIRED AS A FUNCTION OF WINDOW LENGTH
U.S. ONLY - TWO LANDSAT-D SATELLITES

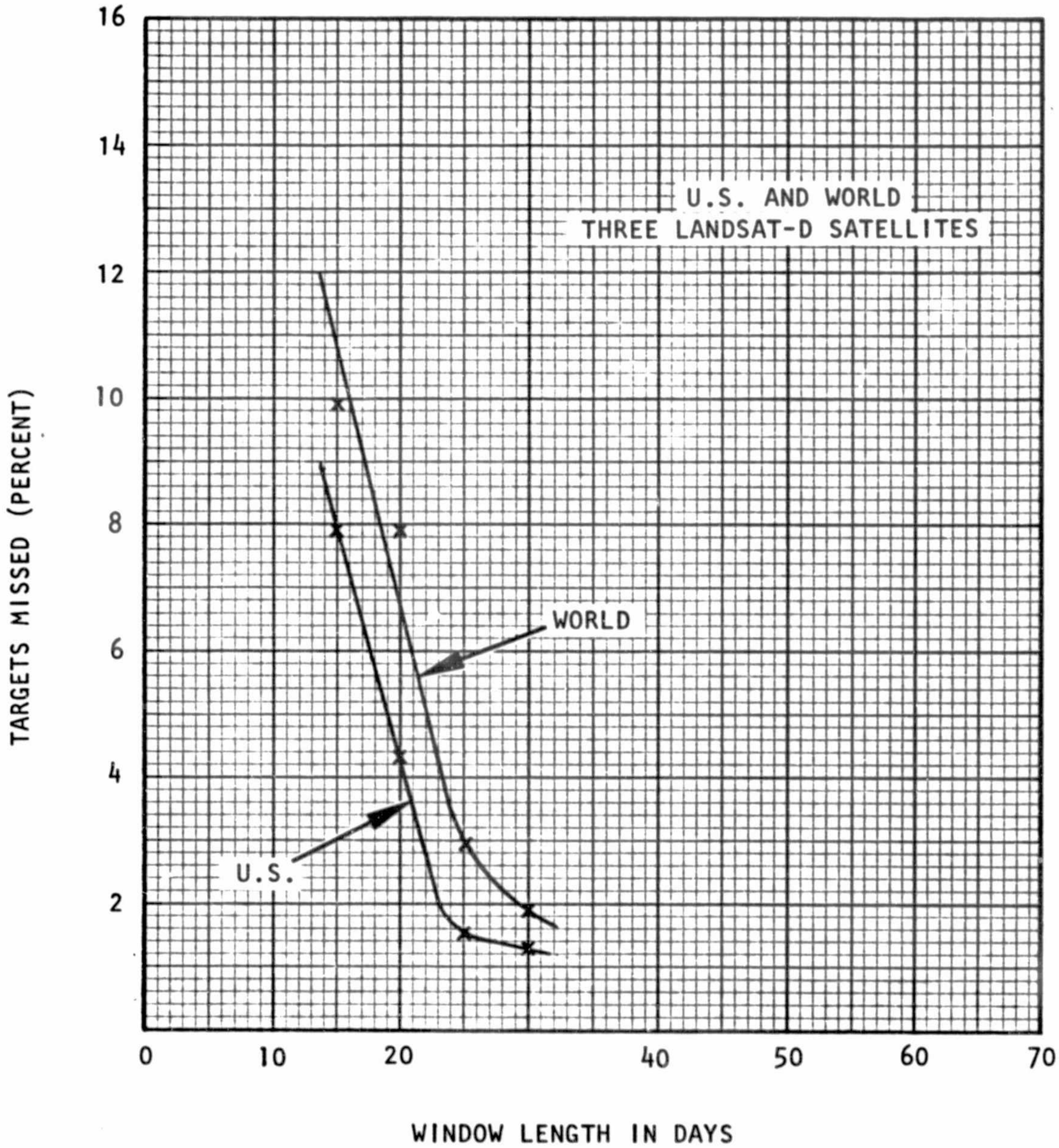


FIGURE 11. SAMPLES MISSED AS A FUNCTION OF WINDOW LENGTH
U.S. AND WORLD - THREE LANDSAT-D SATELLITES

TABLE 6. RELATIVE OBSERVATION PERIOD PER REGION

Country/ Region	Targets Missed (Percent)	Mean Latitude (Degrees)	Overlap	Window Length Mean	Relative Observation Period
Egypt	0	26.6	0.203	63.0	75.8
Australia	0.17	-24.5	0.182	54.0	63.8
Canada	0.17	57.7	1.002	54.0	108.1
Thailand	0.17	12.3	0.101	64.0	70.5
USSR - Latvia	0.06	58.0	1.030	45.5	92.4
USSR - Volga-Ural	0.06	52.0	0.747	48.0	83.9
USSR - Ukraine	0.17	48.5	0.624	55.0	89.3
USSR - Trans-Volga	0.17	50.0	0.674	46.5	77.8
USSR - Siberia	0.78	54.0	0.830	37.0	67.7
Brazil - South	0.09	-23.5	0.173	75.0	88.0
Brazil - North	0.50	-8.0	0.086	67.0	72.8
Japan	0.33	38.0	0.365	64.0	87.4
Argentina	0.44	-32.6	0.276	62.0	79.1
Mexico	0.44	23.5	0.173	69.0	80.9
S. Africa	0.67	-28.3	0.222	62.0	75.8
Romania	1.17	46.0	0.549	45.0	69.7
Italy	1.26	42.0	0.449	45.0	65.2
France	1.50	47.0	0.577	45.0	71.0
Turkey	1.50	38.0	0.365	40.0	54.6
Pakistan	1.67	29.0	0.230	40.0	49.2
Yugoslavia	2.00	44.2	0.501	45.0	67.5
Philippines	2.25	11.0	0.096	64.0	70.1
Indonesia	3.44	-4.5	0.079	45.0	48.6
USA - Region B	1.13	45.0	0.521	44.3	67.4
USA - Region C	3.88	43.0	0.471	41.2	60.6
USA - Region A	4.65	38.5	0.375	31.5	43.3
USA - Region D	5.15	33.6	0.292	37.6	48.6
China - South	1.25	25.5	0.192	40.0	47.7
China - North	2.64	46.5	0.563	40.0	62.5
China - Central	8.42	37.0	0.347	31.5	42.4
Bangladesh	5.66	24.0	0.178	52.0	61.3
India - Punjab	0.78	30.0	0.242	51.0	63.4
India - Coastal	2.16	17.0	0.125	52.0	58.5
India - Bilaspur	5.19	21.3	0.154	44.0	50.8
India - Ganges	8.07	27.0	0.207	41.0	49.5
India - Central	8.30	24.0	0.178	43.0	50.6

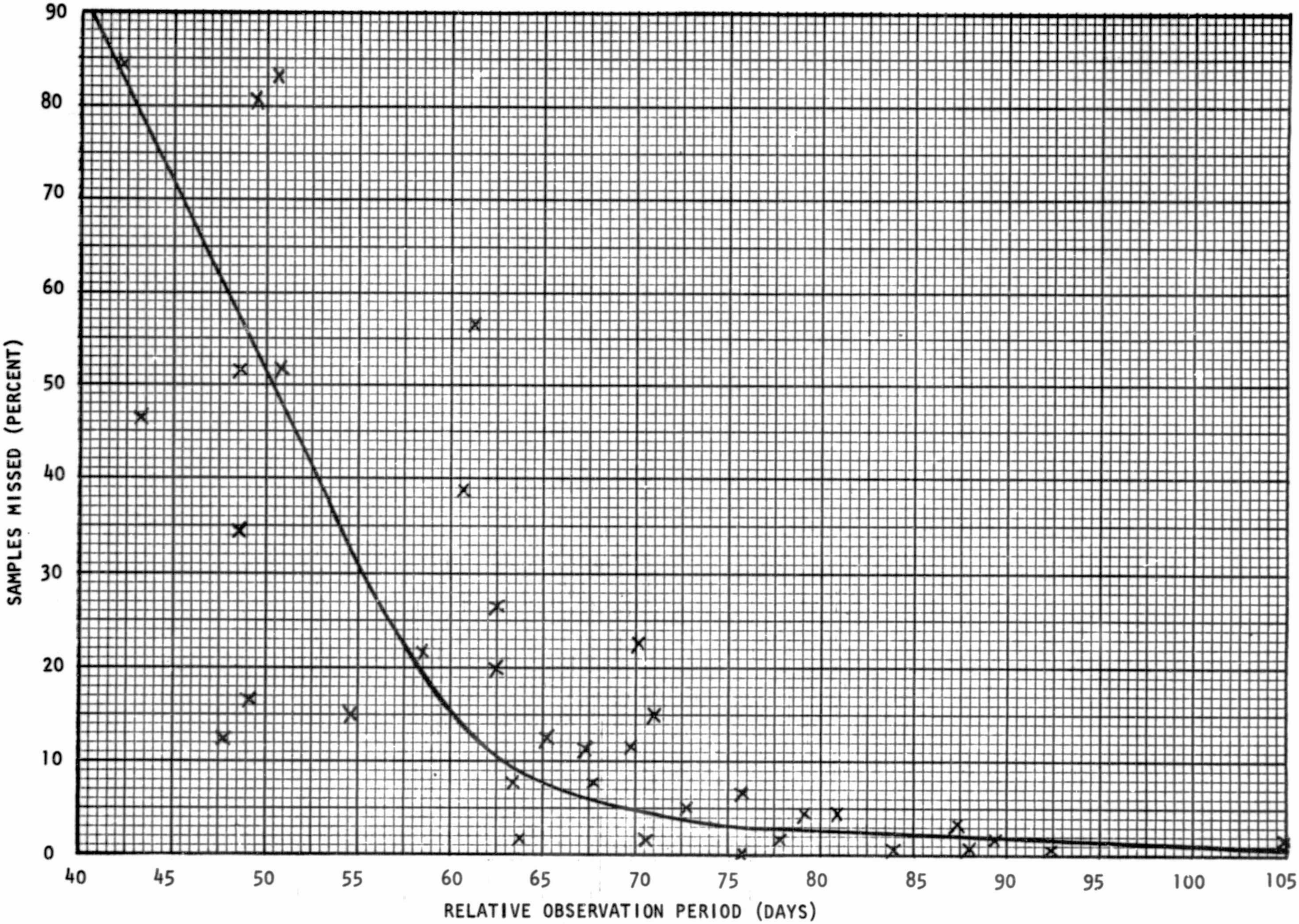


FIGURE 12. SAMPLES MISSED AS A FUNCTION OF RELATIVE OBSERVATION PERIOD BY REGION - TWO LANDSAT-D SATELLITES

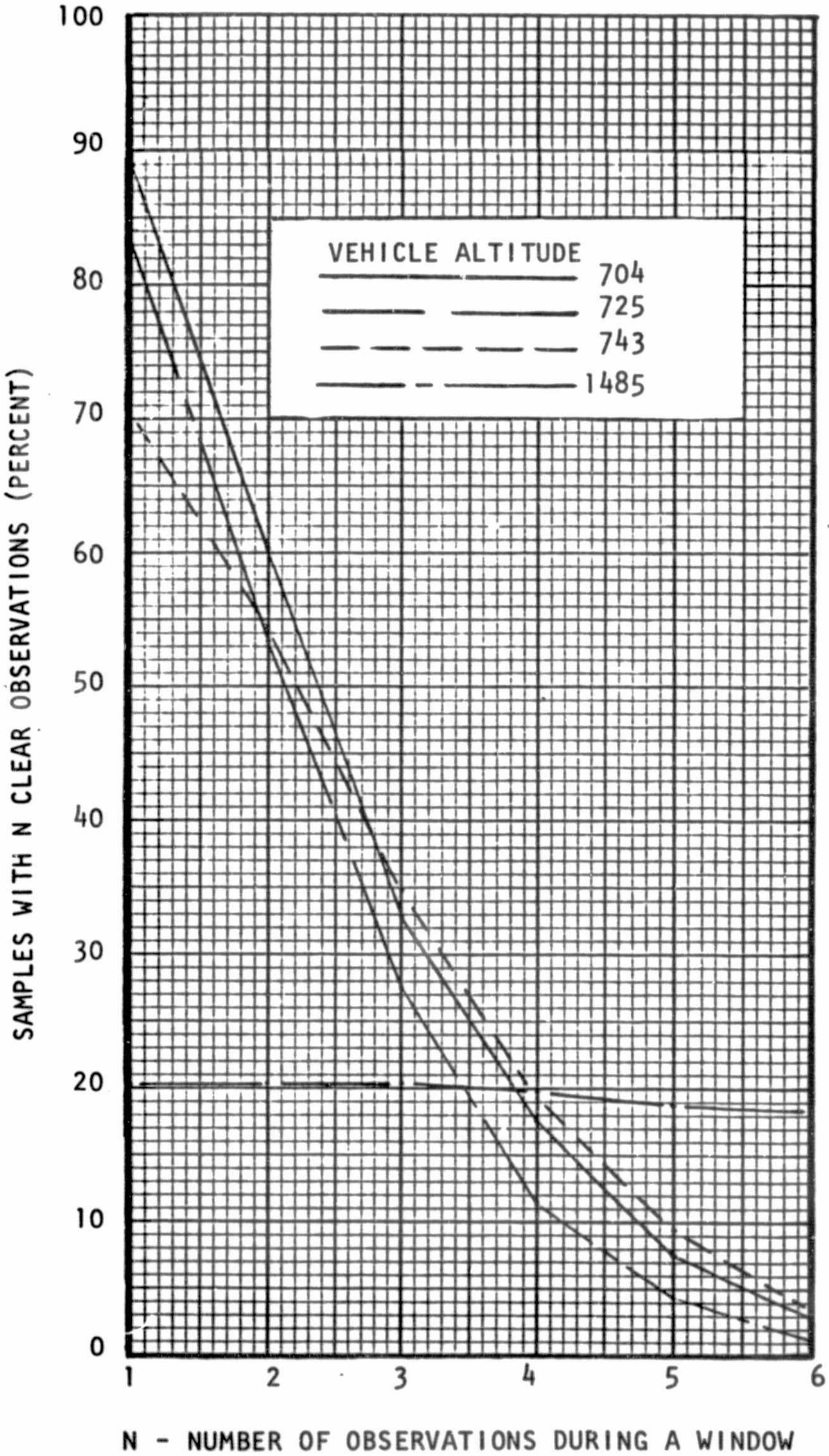


FIGURE 13. CAPABILITY OF OBTAINING MULTIPLE CLEAR OBSERVATIONS FOR VARIOUS ORBITS

for evaluating the extent or intensity of an episode. For total coverage, with one or two observations required during a window, the 704 KM orbit is clearly the best.

Similar plots are shown in Figure 14 for the 1, 2, and 3 satellites at 704 KM, and in Figure 15 for 1 and 2 satellites at 1485 KM. Figure 14 shows that a second clear observation can be obtained for 96% of the targets with three satellites deployed and for 87% if two satellites are used.

ORBIT INSERTION VARIATIONS

Various insertion points were used for each of the candidate orbits to obtain equal time spacing between observations for the full coverage orbits (704 and 1485 KM) and to optimize coverage for the partial coverage orbits (725 and 743 KM). As expected, different insertion points had negligible effect on the capability of obtaining samples for the full coverage orbits.

The insertion point had a significant effect on the percent of samples acquired by the 725 KM (2-day repeat) orbit. The percent of targets observed ranged from 18.2% to 20.4%, thus, the later insertion point viewed 12% more targets than the first.

EQUATORIAL CROSSING TIME

The current and planned Landsat orbits have a 9:30 AM equatorial crossing time. To determine if a later equatorial crossing would increase the probability of achieving the desired samples, three simulation runs were made with 1:00 PM equatorial crossing. The change in cloud conditions between 9:30 AM and 1:00 PM did not have a significant effect. The mean percent of desired samples acquired from the comparison runs is shown below:

Equatorial Crossing Time	Samples Acquired (Percent of Desired)
9:30 AM	99.24
1:00 PM	99.28

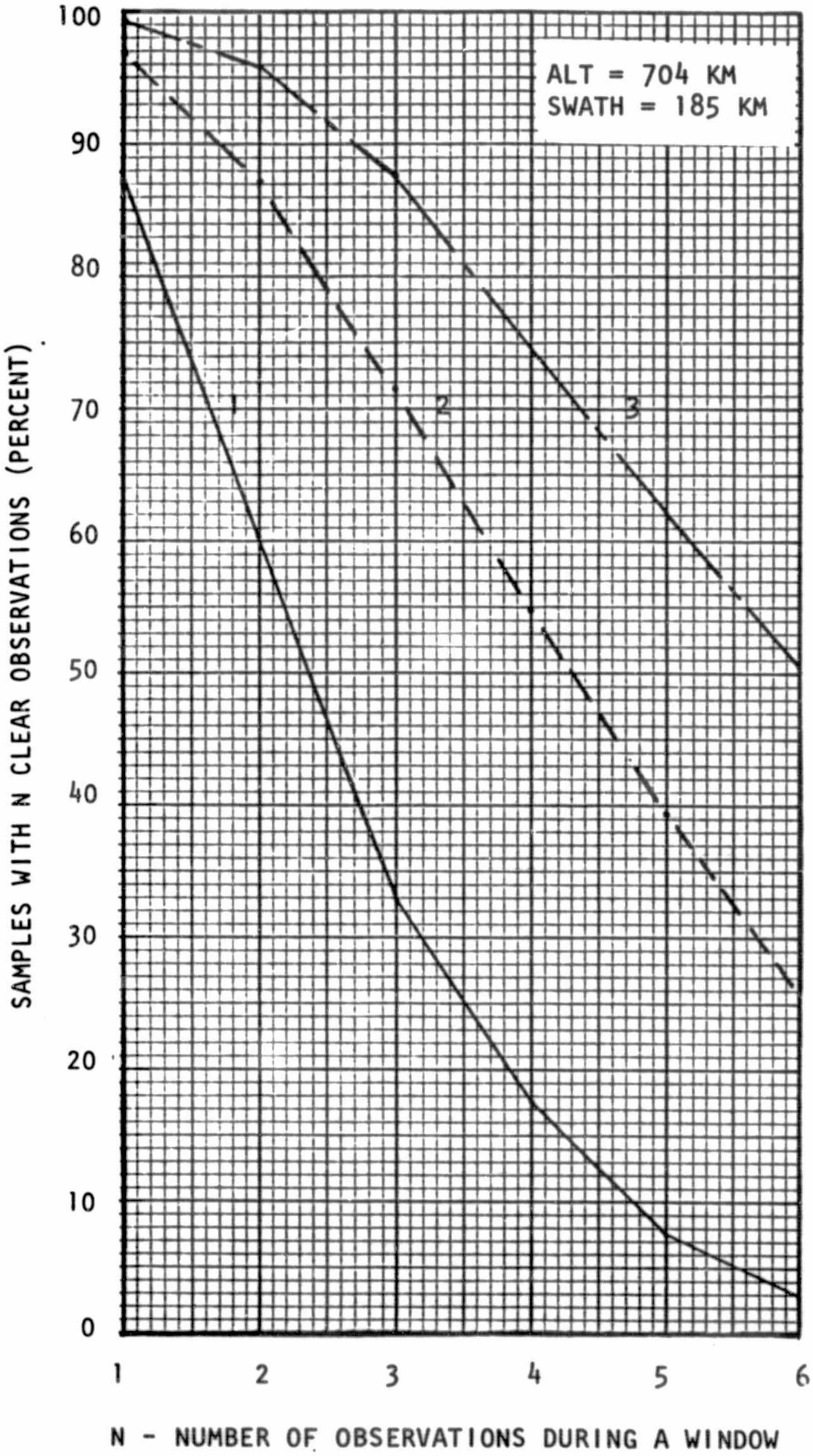


FIGURE 14. CAPABILITY OF OBTAINING MULTIPLE CLEAR OBSERVATIONS FOR 1, 2 OR 3 LANDSAT-D SATELLITES

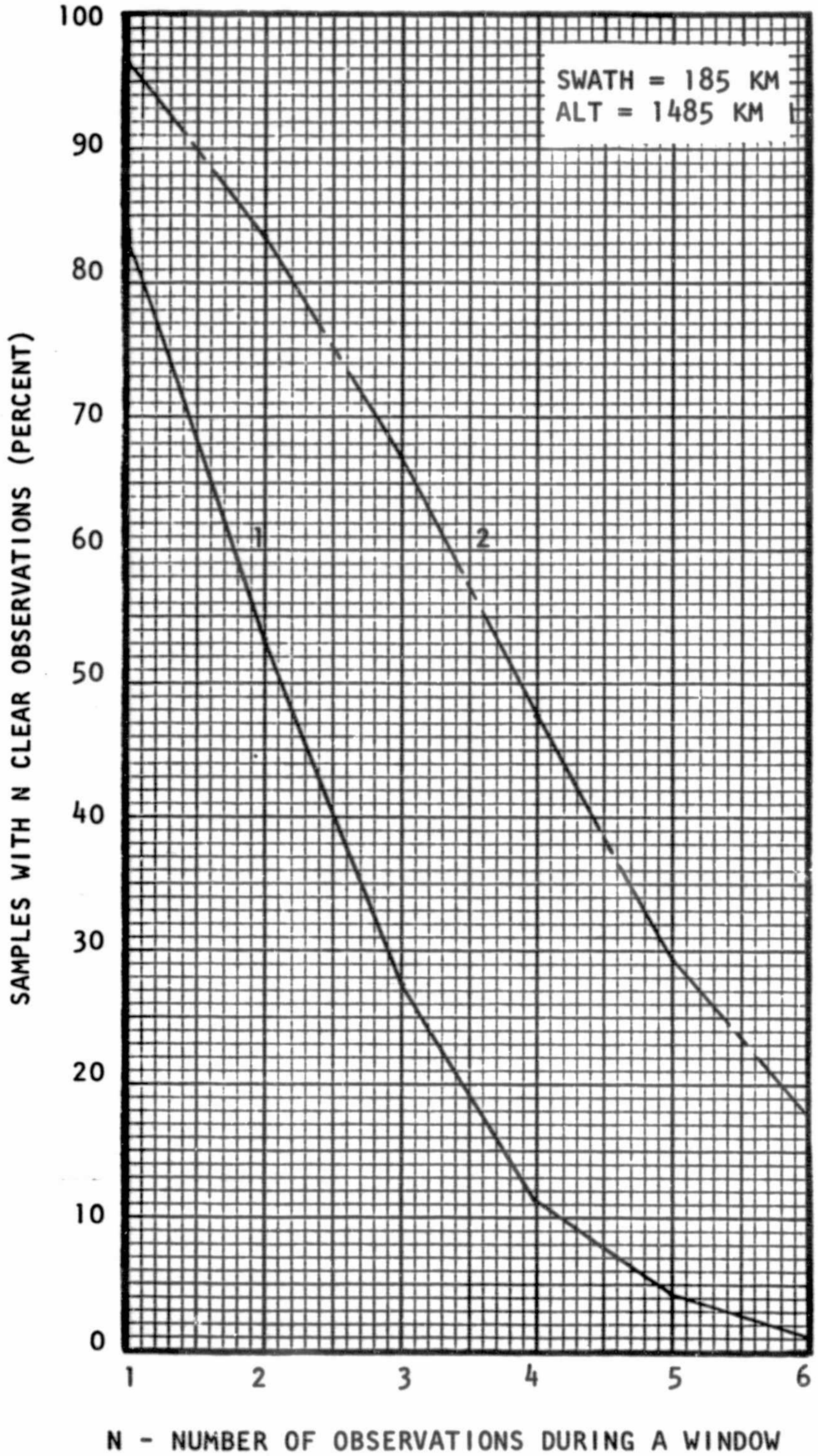


FIGURE 15. CAPABILITY OF OBTAINING MULTIPLE CLEAR OBSERVATIONS FOR 1 OR 2 SATELLITES IN A 1485 KM ORBIT

SUMMARY OF ORBITAL PARAMETER INVESTIGATION

The investigation of the four candidtate systems included the following parametric variations:

- o Orbital characteristics
- o Number of satellites
- o Swath width
- o Cloud cover acceptance
- o Window length
- o Relative observation period
- o Multiple observations
- o Orbital insertions
- o Equatorial crossing time

The analysis to this point is based solely upon data acquisition without regard to data processing volume.

For the purpose of obtaining areal measurement of agricultural land, candidate system 1, consisting of equally spaced satellites at 704 KM performed best. The quantitative relationship between the data acquisition and the various parameters were obtained. Data on the benefits of increased swath was determined and will be suitable for future comparisons of the costs and complexity of increasing the swath. Significant insight into the potential benefits of altering the processing acceptance criteria was obtained. The dependence of performance upon window length and the number of observations required was explored. This data is valuable in extending the results of this study at the time that the needs of the agricultural scientists for remotely sensed image data are better defined. Data was also obtained that showed the results of this study are insensitive to orbital insertion and equatorial crossing time.

IMAGE DATA PROCESSING

The data as acquired by the Thematic Mapper is a sequence of bits representing discrete levels of energy received at different times in different predetermined energy bands. For efficient usage, the band and the pixel represented must be identified by an ordering of the data into a convenient format. Some pixels represent known energy levels and serve as reference points for calibrating the data. Additionally, for agricultural usage, the pixels represented must be identified to some reference system. Each of these functions, formatting, radiometric correction, and registration are considered preprocessing. The amount of computer resources required to perform these functions depends upon the complexity of the function, and the amount of data upon which the functions are performed. By employing a sample extraction philosophy, the amount of data subjected to each succeeding process can be reduced. Part of this study was directed at obtaining realistic data loading at each functional point in the processing system.

YEARLY LOADING FOR AGRICULTURAL USAGE

The sizing and configuration of an operational processing system is dependent upon the time line of data acquisition. Two convenient measures of data volume are acquired scenes and the number of sample segments. A scene represents the 38,027,776 pixels as would comprise an area 185 KM squared at 30 meters spatial resolution. Each pixel represents effectively 5.0625* bytes of data. A sample segment represents 1600 pixels in a desired area one KM square with 44% excess pixels to allow for registration error. A yearly plot representing weekly scene and target acquisition is presented in Figure 16. This data was obtained for the condition of two satellites in a 704 KM orbit, 185 KM swath, an acceptance criteria of 50% or less cloud cover on a scene, and the acceptance of only one observation per target per window. The targets plotted are the simulation targets with a base number of 30 per single crop region. Each 30 targets represents a larger number of samples in an operational system.

*Spectral resolution is 256 levels or one byte/band for five bands at 30 meters spatial resolution plus one band at 120 meters resolution or $(30/120)^2 = .0625$.

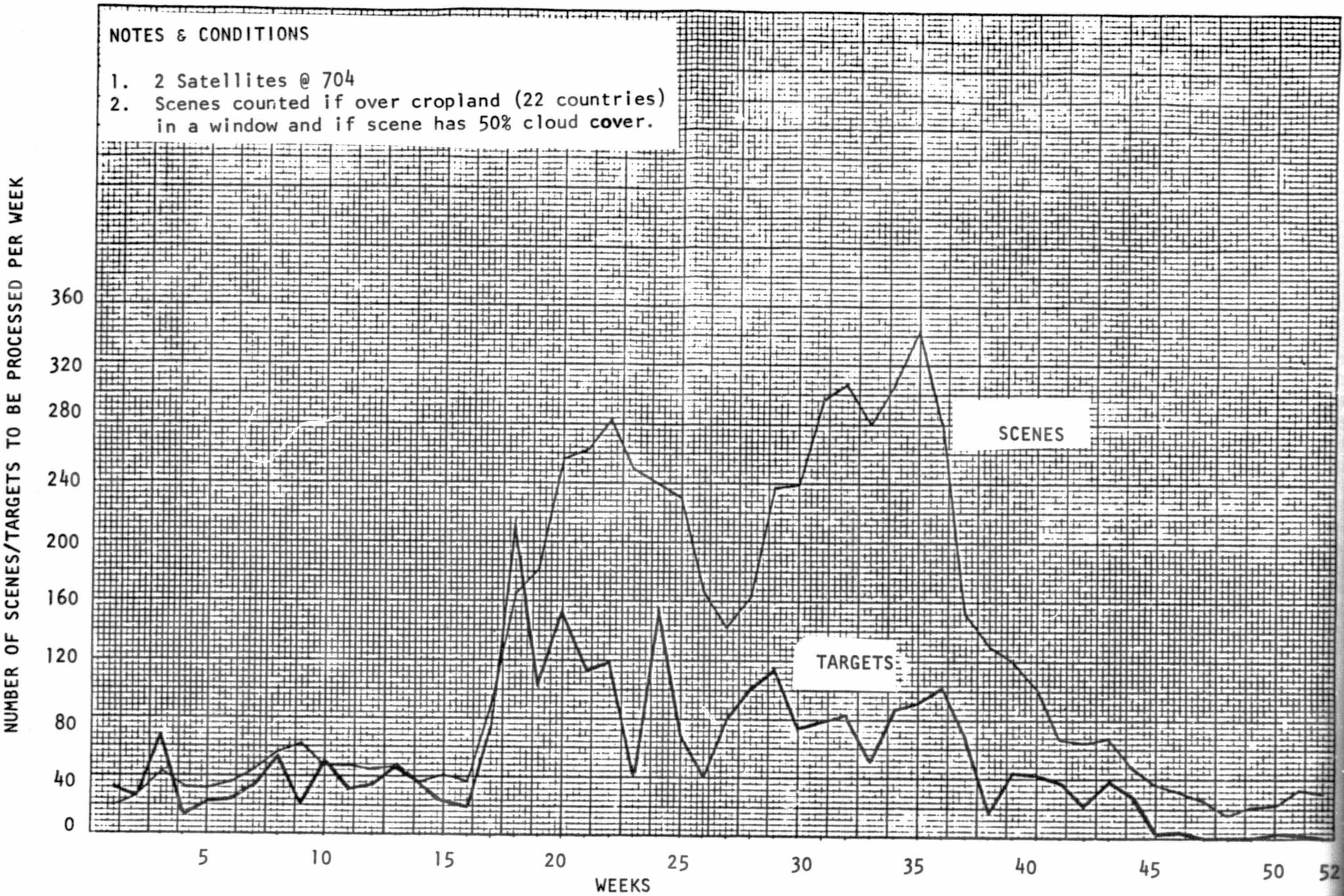


FIGURE 16. WEEKLY SCENE AND TARGET ACQUISITION FOR 1 YEAR

The actual number will depend on the crop densities for the region. A figure of 1,000 samples is a reasonable average and was used in determining processing loads.

PROCESSING SYSTEM DATA VOLUMES

The total number of pixels per year to be subjected to the differing processes was determined for the different candidate systems. This information is shown in Figure 17. What is readily apparent is the small percentage, less than 0.1%, of agricultural information in the acquired data. This factor indicates a need to extract the useful information from the data at the earliest practical time in the sequence of agricultural data processing.

An obvious way to reduce the data volume is to reject images of less than some established quality, as determined by the percentage of cloud cover in the scene. This is the currently accepted operational approach. While it reduces the amount of unproductive activity of preprocessing data that will ultimately be rejected as unusable, it has the detrimental quality of also rejecting some highly desirable data. For the data shown in Figure 17. the acceptance criteria was established at 50%. The subsequent numbers represent data that could be expected in the 50% clear portion of the scenes accepted for preprocessing. Thus, the two columns of numbers; one headed by "Extract Agricultural Samples" which are all of the samples in the accepted scenes, and the other column headed "Edit Cloud Samples", which are only those that are in the clear part of the accepted scenes. The latter column is the yearly total in millions of pixels that can be expected for the different acquisition systems represented by each row in the figure. While the usefulness of multiple observation of the same sample segment is acknowledged, this study placed a premium on the value of the first observation of a sample segment during each of the specified windows. Those observations are represented in the column headed "Process New Information".

CONDITION			ACQUIRE IMAGE DATA USING SATELLITES	EDIT CLOUDY SCENES *	PREPROCESS SCENE DATA	EXTRACT AGRICULTURAL SAMPLES	EDIT CLOUDY SAMPLES	PROCESS NEW INFORMATION	INFORMATION AS % OF ACQUIRED DATA	PERCENT OF DESIRED SAMPLES ACQUIRED
NO. OF SAT.	ALTITUDE IN KM									
1	704	185	189568	119331	424.7	320.4	136.0	.0717	87.11	
2	704	185	381609	242731	854.1	646.0	151.2	.0396	96.99	
3	704	185	563724	358450	1273.3	958.7	154.8	.0275	99.15	
1	1485	185	164166	102789	365.9	281.9	130.0	.0792	83.12	
2	1485	185	327952	207251	731.4	548.7	150.6	.0459	96.51	
1	704	222	215199	134086	499.0	392.2	144.3	.0671	92.48	
2	704	222	429258	271443	1012.7	755.7	152.6	.0355	97.78	
1	1485	222	267995	168113	442.8	344.6	140.4	.0524	88.88	
2	704 & 743	185	375106	239005	828.7	628.5	150.8	.0402	96.65	
2	704 & 725	185	387427	243416	890.2	668.2	137.3	.0354	87.97	

*MAXIMUM OF 50 PERCENT CLOUD COVER IN A SCENE ACCEPTED FOR PREPROCESSING.

FIGURE 17. A COMPARISON OF SATELLITE EFFECTS ON DATA VOLUME FOR PROCESSING

COMPARISON OF CANDIDATE PROCESSING SYSTEMS

A knowledge of the data volumes at each functional location is necessary to size the processing system. The required processing system will influence the choice of the data acquisition system. Nevertheless, the mission suitability of any given system must be measured in terms of its ability to acquire the required data. Because of regional variations discussed earlier, any single figure of merit such as those numbers in the column headed "Percent of Desired Samples Acquired" should be used cautiously. However, they do provide an additional dimension in addition to data volumes and the information to data ratio, by which the candidate acquisition system may be judged. A goal established early in the study was to acquire 98% of the desired samples. Only the three satellites system does that, although others come close. When the incremental cost of three versus two satellites is taken in perspective, there is ample room to investigate other remedies. Oversampling is one serious consideration.

OVERSAMPLING TO COMPENSATE FOR MISSED SAMPLES

The concept of sampling assumes the samples are randomly distributed such that they faithfully represent the parent population. Some distortion will be introduced if the missed samples are not randomly missed. Because cloud conditions are the major factors in missed samples, it is unlikely that the samples will be randomly missed. It is for this reason that this investigation includes regional cloud statistics. Based upon the resolution of the simulation, no statistically significant variations within a region could be detected. This is not surprising for the resolution of the cloud model used. Statistical variations from region-to-region were evident and were considered when determining the loading effects of oversampling. Before any oversampling procedures could be implemented, it is necessary to ascertain the intra-regional biases in the missed samples. This could be done with additional simulations on a smaller scale with regionally refined cloud data. The data from this study indicates a potential to reduce the scope of the study to selected regions.

Another consideration in applying oversampling is the need for multi-temporal classification. This concept implies that it is not possible to classify accurately from a single observation. Thus, multiple observations would be required for each sample and would necessitate an even greater overage for each subsequent observation. The amount of oversampling is a function of the percent missed raised to the power of the number of observations required. This was not included in the loading consideration of this study since only one observation per window was used.

A third factor to be considered in designing an oversampling strategy is the desired confidence level for obtaining samples. For this study the design goal was to achieve the required samples 19 out of 20 years or a 95% confidence level.

Figure 18 includes the data volumes within the agricultural processing system when oversampling is used. The oversampling numbers were determined using the regionally weighted data obtained by simulation. The number of extra samples required for each region was determined based upon the mean plus 1.65 sigma of those samples missed in each region.

SCENE CLOUD EDITING

The concerns of bias resulting from oversampling lead to a desire to minimize the oversampling requirement. The oversampling percentages are indicated for each line in Figure 18. The dramatic reduction in the percentages is evident when the samples are extracted from up to 90% cloudy scenes. This indicates a very real trade-off in processing costs versus either additional satellites or oversampling bias. The processing penalty is in the data volume to be preprocessed. Unfortunately, the limits on the amount of oversampling permitted without excessive bias are not currently available to guide the assessment of the worth of the additional processing. Fortunately, as the processing is moved closer to the source, including the ultimate of onboard, the vehicles, the concept of editing cloudy scenes vanishes with the entire scene concept.

CONDITION: NO. OF SAT.	CONDITION: ALTITUDE & SWATH IN KM	ACQUIRE IMAGE DATA USING SATELLITES	EDIT CLOUDY SCENES *	PREPROCESS SCENE DATA	% OS	EXTRACT AGRICULTURAL SAMPLES	EDIT CLOUDY SAMPLES	PROCESS NEW INFORMATION	INFORMATION AS % OF ACQUIRED DATA	PERCENT OF DESIRED SAMPLES ACQUIRED
1	704 Alt. 185 Swath	189568	50	119331	0	424.7	320.4	136.0	.0717	87.11
					33.5	567.0	427.8	156.0	.0823	100.00
			90	176259	0	622.1	382.8	143.8	.0759	92.14
					18.1	734.7	452.1	156.0	.0823	100.00
2	704 Alt. 185 Swath	381609	30	182153	0	640.4	518.9	146.8	.0385	94.20
					14.8	735.2	595.7	156.0	.0409	100.00
			50	242731	0	854.1	646.0	151.2	.0396	96.99
					8.2	924.1	699.0	156.0	.0409	100.00
			90	354305	0	1246.2	746.9	154.2	.0404	98.84
					3.2	1286.1	770.7	156.0	.0409	100.00
3	704 Alt. 185 Swath	563724	50	358450	0	1273.3	958.7	154.8	.0275	99.15
					2.2	1301.7	980.1	156.0	.0277	100.00

* MAXIMUM PERCENTAGE OF CLOUD COVER IN A SCENE ACCEPTED FOR PREPROCESSING.

OS INDICATES OVERSAMPLING TO OBTAIN 100% OF DESIRED SAMPLES 95% OF THE TIME.

FIGURE 18. A COMPARISON OF EDITING EFFECTS ON DATA VOLUME FOR PROCESSING

COMPARISON OF PROCESSING COSTS

The previous discussion focused on processing variations in the maximum percent of cloud cover acceptable in a scene for preprocessing and the extraction of agricultural samples. Some dollar estimates are presented in this paragraph as a means for comparing the relative costs of each approach. The basis for comparison is the peak processing required during any two week period. Peak load impacts the processing system sizing and cost. The peak two week load was determined for the two 704 KM satellite acquisition period and the subsequent boards in successive downstream processes were determined for three cloud editing strategies.

The rational used was to develop a system concept for the nominal case and normalize the gross order of magnitude cost on a per magapixel basis. The acceptance of 50% cloud covered scenes for preprocessing was considered nominal.

The relative processing costs for the 30, 50 and 90 percent cloud cover acceptance is illustrated in Figure 19. The agricultural processing is shown for the situation of processing all usable information through the models and only one sample set per window. In all cases the samples are square 1.2 KM on a side.

The relative performance of each startegy is measured as a percentage of targeted samples obtained. For a performance improvement from 94 to 99 percent, the relative processing cost increases from 236K to 517K. This provides a strong argument to evaluate the efficacy of oversampling.

The relative processing costs for each of the editing strategies and oversampling are portrayed in Figure 20. The results of processing oversamples do not appreciably affect the processing cost. By the measure of performance used, each strategy is equal. The basing effects of oversampling needs to be further investigated before a conclusion on the most desirable editing strategy can be stated.

TWO LANDSAT-D SATELLITES WITH DIFFERENT EDITING STRATEGY

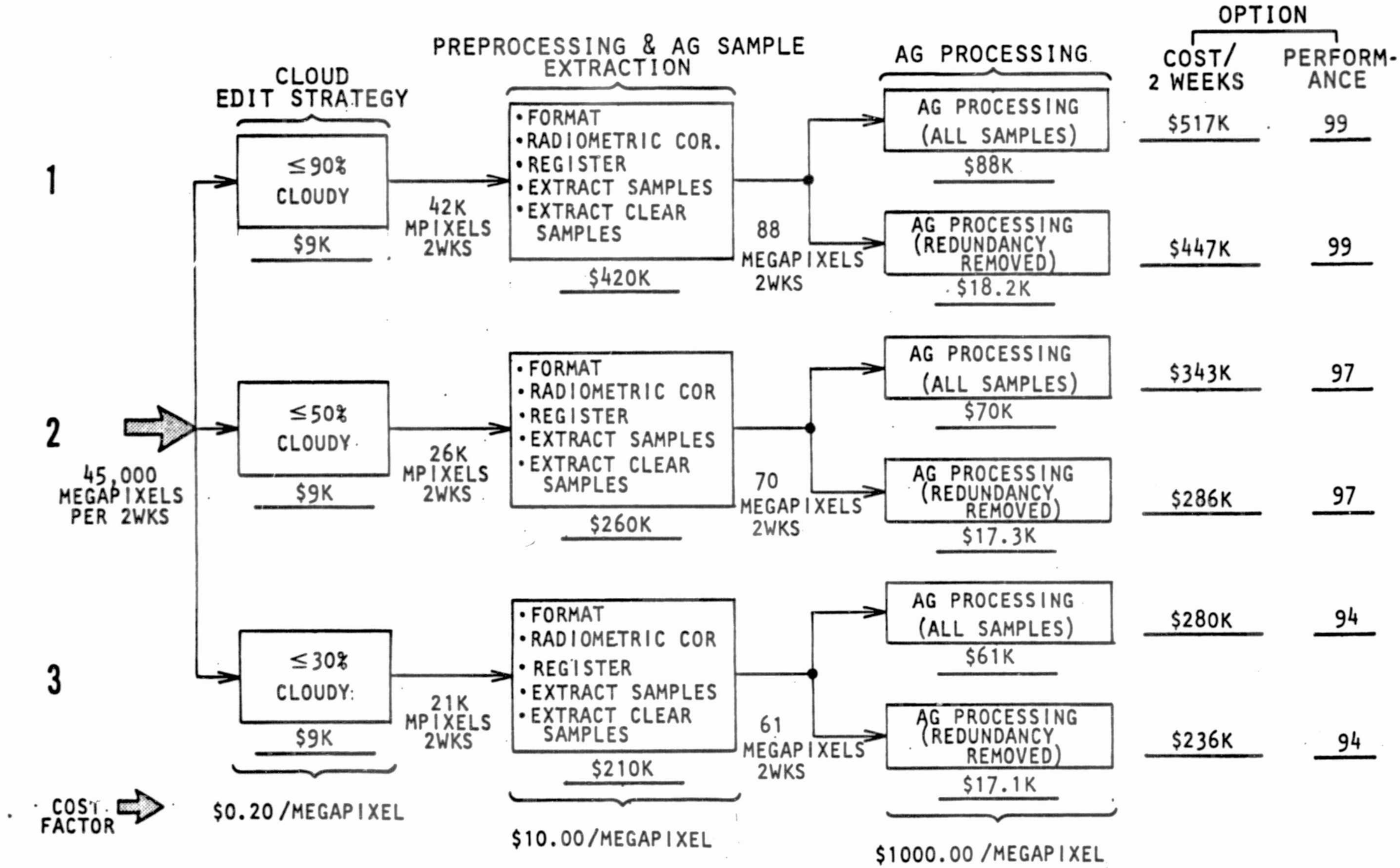


FIGURE 19. DATA FLOW & COST COMPARISON

TWO LANDSAT-D SATELLITES WITH DIFFERENT EDITING STRATEGY

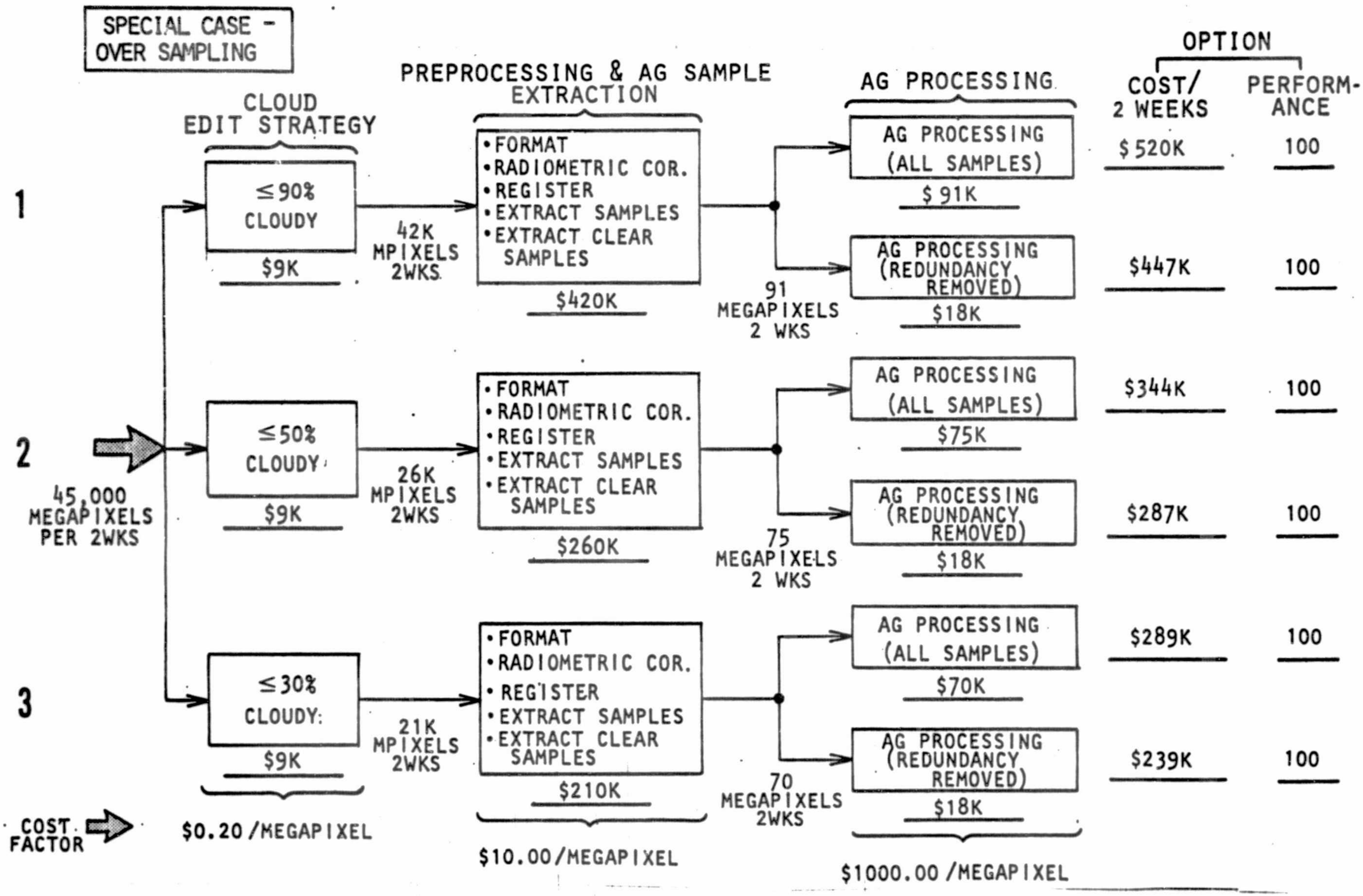


FIGURE 20. OVERSAMPLED DATA FLOW & COST COMPARISON

AN AGRICULTURAL DATA SYSTEM

A simplified concept for an agricultural system employing processing on-board a dedicated agricultural satellite is portrayed in Figure 21. This system concept is suggested by the results of this study. It is presented as a concept for future analysis and has not been subjected to detailed scrutiny. The availability of the collateral data, the collateral data acquisition system, the size and the content of the agricultural database, and the nature of the agricultural models and feature extraction algorithms have not been unambigously defined.

The significant findings of this study do indicate the viability of this concept. The nominal Landsat-D orbit appears to be the optimal choice. The time of the equatorial nodal crossing needs additional study.

The significant reduction in data communications and processing requirements by early sample extraction is justification for considering on-board extraction. This reduction in the data transmission requirement will make a wider swath than 185 KM feasible. The precise orbital and platform stability availabile with the Landsat-D series of spacecraft will permit registration on-board by means of predetermined mission timelines. The ability to update the sample definition is essential considering that the sampling strategy will evolve and can only be optimized by the use of operational system.

An important simplification of the ground processing will result from a reformatting of the data into sample segments. Subsequent lines of scan data will contain portions of several segments. The development of sufficient on-board buffers to accumulate an entire sample segment is a practical solution to reduce the identification process. Capacity for several samples to be constructed simultaneously will be required.

On-board radiometric correction is relatively straight-forward. It should be done on a scan-by-scan basis prior to the formatting into sample segments. It will also be simple to incorporate a cloud editing check since the acceptance criteria at the sample segment level is either clear or cloudy. One-hundred percent cloudy samples would be detectable by the brightness threshold.

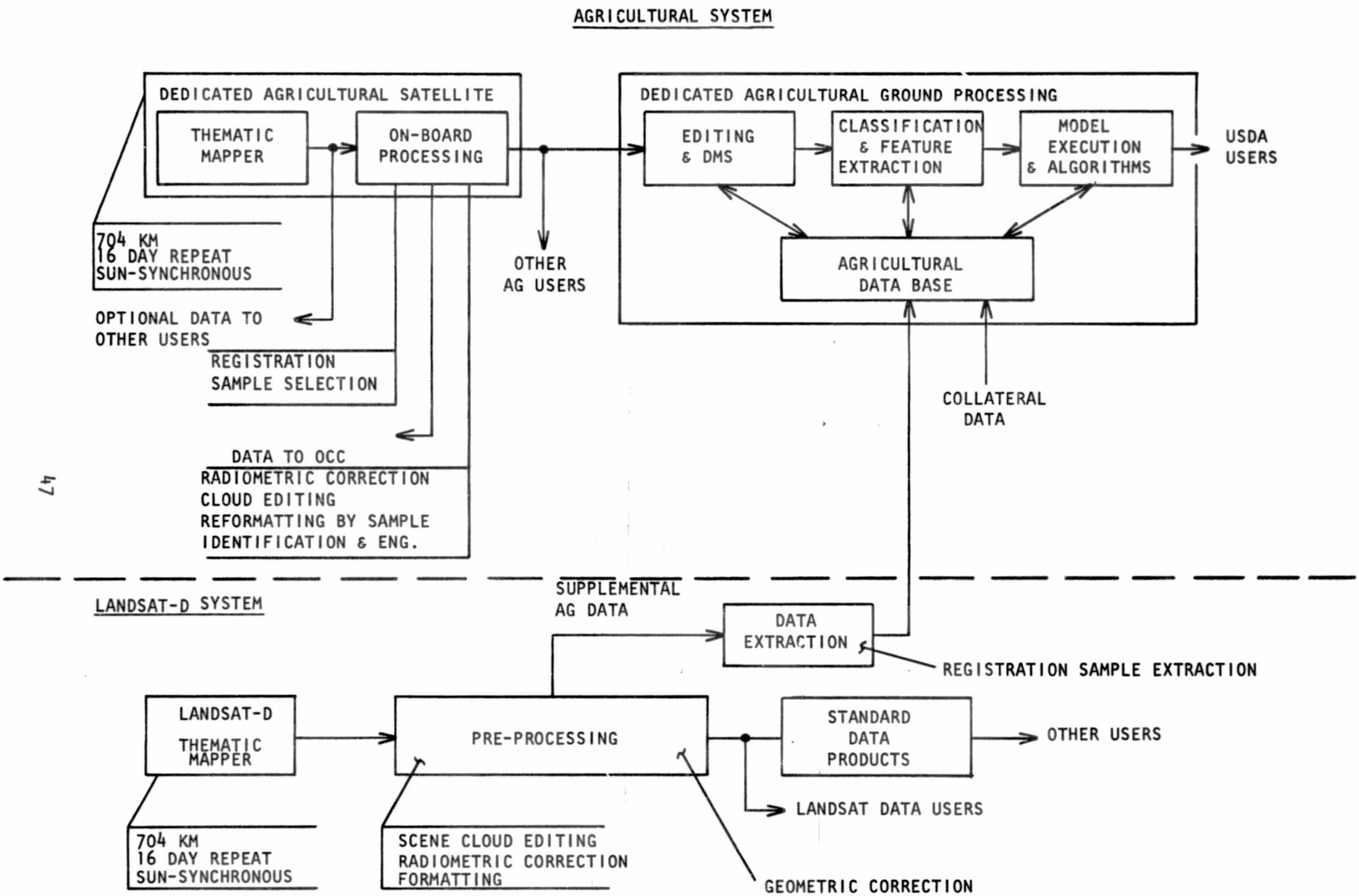


FIGURE 21. SYSTEM CONCEPT FOR AGRICULTURAL APPLICATION

It would also be desirable to incorporate some by-pass logic to down-link selected portions of the data at various stages in the on-board process for engineering varification at the OCC. This system would be used selectively for calibrating purposes and would not be expected to impose any additional requirements on the communication channel.

The suggested system concept would use supplemental data from the planned Landsat-D system. One use of the supplemental data is for the inventory of all land to detect the introduction or loss of agricultural land. This could be on an infrequent period of once every 2 to 5 years. Samples extracted from the standard Landsat-D processing system could also be used to supplement the sample acquisition as well as for episode assessment. The size of these samples may be different from those extracted on-board the dedicated agricultural satellite. The extraction of agricultural data would be done prior to the application of any geometric correction resampling.

SUMMARY

When the problems and cost of data processing are factored into the results from the data acquisition investigation, one conflict is apparent. Better successes are achieved by relaxing the cloud conditions acceptable for preprocessing. Lower costs of processing are achieved by making the acceptable cloud conditions more stringent. This highlights the need for more detailed studies in this area of conflict. Some potential resolutions, of which the feasibility is still in question, are the use of oversampling or floating sampling techniques and dedicated satellites with special sensors and on-board processing. The costs of development, as well as the technical practicality, must be included in any future study of these alternatives.

APPENDIX A

ALTERNATIVES TO ADDITIONAL SATELLITES FOR ACQUIRING THE NEEDED INFORMATION WITH A MINIMAL LOADING ON THE GROUND PROCESSING SYSTEM

Many factors in a satellite borne image data system affect the number of satellites required and the amount of ground processing required. The factors are coupled such that a change in one parameter will also require a change in other parameters. A qualitative analysis of factors impacting either the number of satellites or the amount of ground processing required to perform the agricultural mission was performed. The major factors are discussed below. They were considered in baselining the candidate systems investigated in this study.

RELAX REQUIREMENTS

The requirements for agricultural image data comprise; 1) the crop species, 2) the makeup of the regions for which the forecast is required, 3) the use of the data for inventory, yield, or episode assessment, and 4) data quality which includes the number of spectral bands, spatial resolutions and spectral resolution.

The crop species of interest, including confuser crops, affect the frequency and the time criticality of the observations. Relaxation of this requirement would have more impact on the volume of data to be processed than on the number of satellites required. For the four crops investigated (wheat, soybeans, corn, and rice), no impact could be determined on the number of satellites required. The most significant influence crop species has is its effect on the duration of the window during which observations are made. This in turn affects discrimination accuracy. This factor is closely related to the data quality requirement. The deletion of crops that grow in diverse climates such as tropic, artic, or swampland has a slight impact on the total area involved.

The makeup of the reporting regions has a significant impact on the amount of data required to attain a given reporting accuracy. As Castruccio explains$_{(8)}$, number of samples required for a region is a function of accuracy

and not the size of the region. For some regions it is inherently more difficult to obtain the required images because of climatological and geographical considerations. The orbital parameters are such that regions further removed from equatorial latitudes have more frequent opportunities of observations due to the overlap in the sensor field-of-view from orbit-to-orbit. Difficult regions were determined using simulation.

The intended use of the image data impacts the number of satellites required. The use of remotely sensed image data for inventory of the amount of land planted in a particular crop is easier than to determine the production of a crop before harvest. In the former case, only enough observations are required to classify the data.* The greatest influence by the use of the data, is on the timing of the observation, or window length. The windows used for this study were based on a mensuration requirement. In this case, the shortest duration of opportunity was 17 days. When yield and episode requirements are added, some of the windows may be as short as 4-days. While this situation was not determined as the baseline for the simulation, some considerations were given to accommodating such requirements in a maturing system.

Data quality was not specifically addressed in this study. The general relationship of data quality to the data volume and the number of satellites required was analyzed. Some generally accepted values were assumed. The number of spectral bands affects the data volume in a deterministic way. The spatial and spectral resolution requirement affect the number of satellites needed in a rather complex relationship of basic sensor response, integration times, and the area over which the light is collected. The number of satellites required is dependent upon the ability to observe a particular location at a particular time. As the swath is increased, more locations are in a favorable position at a given time. But the swath can be increased either by enlarging the spatial resolution, bigger steps between integration, or decreasing the integration time.

*This statement is not entirely true as it applies to sensor resolution, but for this study, existing sensor systems were assumed.

The latter decreases spectral resolution. For this study, 128 levels of 30 meter IFOV was assumed.

ALTER ORBIT

Alterations in the orbits of the satellites impact the number of satellites required. The alterations may take the form of; 1) frequency of return over a particular location, 2) inclination which affects the percentage of time over crop regions, and 3) swathing which affects the sequence of orbit-to-orbit and day-to-day locations of the satellite.

The frequency of the return,or repeat cycle,is a function of altitude and inclination. If 100% coverage of the world is assumed, then the number of orbits required depends on the swath width of the sensor which was nominally assumed at 100 nautical miles. This is the swath width of the currently planned Thematic Mapper which is scheduled for use on Landsat-D. The lower altitudes have a shorter period and for the same number of orbits will repeat in fewer days. Altitude is limited in the low value by atmospheric drag and the angle required with the earth surface when the sensor is at the edge of a swath.

The angle of illumination of the cropland by the sun during data taking affects the classification algorithms. For simplicity a constant sun angle is desired and it is obtainable by a proper choice of inclination selected orbital period. Since even for non sun-synchronous inclinations, half of each orbital period would not be illuminated and thus only be suitable for limited infrared data, no great advantage was determined for lower inclination orbits. The detailed investigation of orbital effects using simulation was confinded to sun-synchronous orbits.

Swathing variations include the time sequence of adjacent swaths and any uneven distribution of the swaths. The time sequence is particularly interesting as it related to the conditional nature of cloud conditions. When a cloudy region is encountered at time T-zero, there is a high probability a cloudy region will be encountered adjacent to that region at T-one if the adjacent region is close and if T-one is not too long after T-zero. For most of the

orbits of interest to agriculture, the time between orbits is of the order of one and one-half hours. Likewise, when clear observations are attainable at one time and place, they are also likely at other nearby places within a short period of time. While the net effect may not completely cancel, it is not likely to materially affect the number of satellites required. Of greater interest for the agricultural missions is the capability to obtain repeat observations of particular areas at selected times. Such effects were studied using simulations of short repeat cycle orbits; specifically, 2-day and 9-day.

USE A POINTABLE SENSOR

The ability to point the sensor at a specific target greatly increases the opportunities to obtain needed information. The amount of pointing considered in this study was limited to one swath width to avoid the complications of classifying data obtained at a low grazing angle with the earth's surface. Along track pointing also gives an additional dimension for classification by taking advantage of anatropic signature discrimination. However, the complexity of this relationship to the number of satellites required was beyond the scope of this investigation. Any system or component requiring redesign was rejected for detailed consideration unless the benefits were outstanding. Consequently, the effects of sensor pointing were limited to cross-track positioning of the currently designed Thematic Mapper.

INCREASE THE SENSOR SWATH

The swath width used bears directly on the number of satellites required. Wider swaths permit greater spacing between swaths, which results in fewer orbits to cover the earth. Thus, more frequent observation opportunities are available for a given number of satellites. Any significant change in the swath from the 185 KM of the Thematic Mapper will require a sensor redesign. Either more data is required or less spatial resolution is obtainable. The consideration of swath width is related to spatial and spectral resolution discussed under requirements. Alternatives of increasing the number of sensor

primary elements and sensor complexity were not considered viable. Simulation studies of minor swath increases were performed. A 20% increase in swath width (to 222 KM) should be achievable with only minor changes in the present system.

USE BETTER GROUND TRUTH

Better ground truth was considered to have a bearing upon the number of satellites required as it relates to the number of observations required to obtain sufficient classification accuracy. A consideration was the inclusion of an area of high spatial resolution within each image. The resolving power would be increased optically. An example might be an area 90 meters by 90 meters within each 185 KM square image. The resolution of each picture element or pixel was assumed at 30 meters. Within the 90 meter squares, one meter spatial resolution might be used to establish a training set for classification of the larger image. The assumption being that the increased resolution (one meter over 30 meter) would permit an accurate classification of the 90 square meter area. This area would serve as a training set for the nine 30 meter pixels taken for that area which would be coincident in time and within the spatial confines of the image. Insufficient data was available to assess quantitatively the effect this would have on the number of satellites required. Once the effect on classification is determined, the results obtained for the assumed classification requirements can be scaled.

USE SAMPLING STRATEGIES

The effective use of sampling strategies achieves both a reduction in the amount of data to be processed and the number of satellites required. Only a small percentage of the data obtained will be used in the agricultural forecasting models. The selection of the right data by sampling at the data taking phase effectively reduces the data. The statistical nature of the data and the chance occurrence that the data will not be rendered useless because of cloud cover places an increased demand on the number of observation opportunities required. An acceptance of the condition that less than all the

desired samples will be obtained reduces the pressure for more satellites. Then, an oversampling strategy can be employed such that an attempt is made to obtain more samples than are actually needed. This requires the assumption that the designated samples contain equally valid information. This limits the application to some small percentage of the total samples. For an arbitrary limit of 10%, success can be claimed in meeting the requirement whenever the number of satellites employed obtained 90% of the targets specified. Thus, if 98% of the samples were required to achieve a given mensuration accuracy, and the simulation showed 92% obtainable with two satellites, oversampling strategies would call for an attempt at acquiring 108.7% of the number of desired samples. The penalty is an increase in the amount of data to be processed for the benefit of requiring fewer satellites.

PRIORITIZE DATA ACQUISITION

The nature of the agricultural mission places a temporal value on the information obtained. There is also some value to second and third observations of basically the same images because they help reduce classification errors. There is a trade-off between redundant observations and the cost of additional capability to process them. A priority strategy will maximize the information throughput for a given processing capacity.

The use of a priority system for data acquisition indicates a close coupling between the acquisition subsystem and the user models since the data value will dynamically change according to user model needs.

EDIT ON IMAGES

Certain preprocessing, which as a minimum, includes the correlation of the image data to time and position via spacecraft engineering data, must be performed on all usable data. Radiometric correction may also be included in the preprocessing. To minimize the amount of unproductive preprocessing, some early image editing is desirable. The exclusion of 100% cloud covered

images is a reasonable way to reduce the amount of processing performed on data with little likelihood of producing usable information. As the quality requirements of a scene acceptable for processing is increased, the proportion of useless processing decreases. The overall success in acquiring a specified number of samples for a fixed number of opportunities, (as a function of the number of satellites used) will also diminish. The quantifications of these effects was done using simulation.

INHIBIT ACQUISITION OF POOR QUALITY DATA

The development of a sensor system to perform editing at the point of origin will reduce the processing even more. The approach to this alternative is to quantify the reduction obtainable at each point in the system without regard to the technology or cost of performing the reduction. The resulting benefits will provide a potential measure of the worth of alternative systems.

USE STABLE PLATFORM

The use of an ultra stable platform to minimize registration difficulties and the amount of geometric correction was considered. The current projection for Landsat-D when combined with about a one KM square sample segment were considered justification for not considering geometric correction as a necessary part of agricultural processing.

IMPROVE PROCESSING

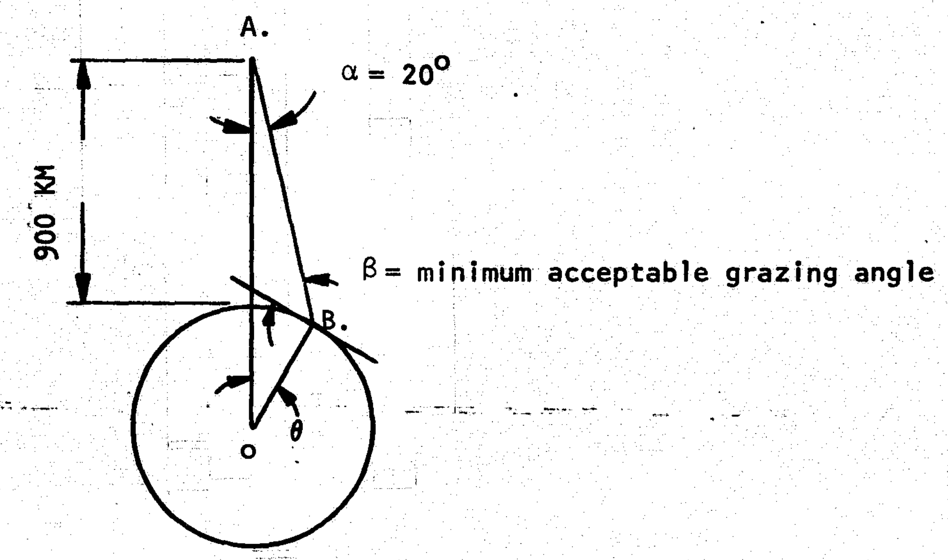
An improvement in processing is a definite alternative to the problem of editing and ground processing. It also can take various forms ranging from a reduction in the number and frequency of inputs required to the models to more efficient classification algorithms. While admitted as an alternative with great potential, it was deleted from consideration in this study. Any improvement will benefit the system in addition to the recommendations from this study, without rendering the study eccentric to the other alternatives considered.

APPENDIX B

MAXIMUM SWATH WIDTH AS A FUNCTION OF ALTITUDE

Precise information on the maximum off-nadir angle that is acceptable for agricultural images is not available. Some guidelines are extrapolated from experience with Landsats 1 and 2. For a nominal 900 KM altitude the maximum usable off-nadir angle was found to be 20 degrees.

Earth Radius = 6378.165 KM



Expressing the line A-B in earth centered coordinates yields $y = mx + b$ or $y = -2.747477419x + 7278.165$.

Expressing the earth as a perfect circle yields $x^2 + y^2 = r^2 = 40680988.77$

Solving the two equations for x and y yields

$$x = 330.6956$$
$$y = 6369.58251$$

This yields a solution of $\theta = \tan^{-1}\frac{x}{y} = 2.97201^{\circ}$

The minimum acceptable grazing angle β is then found by the geometry of the sum of the interior angles of a triangle equal 180^{o}.

$$\beta = \beta' - 90 \text{ where } \alpha + \theta + \beta' = 180$$
$$\text{or } 20 + 2.97201 = 180$$
$$\beta = 180^{o} - 20^{o} - 2.97201^{o} - 90^{o} = 67.03$$

To obtain the general relationship of altitude as a function of θ as constrained by a minimum β of 67.03^{o}, it is necessary to apply the sine law:

$$\frac{A}{\sin\alpha} = \frac{B}{\sin\beta} = \frac{C}{\sin\gamma}$$

Then $\dfrac{\text{radius of earth + altitude}}{\sin(90+67.03^{o})} = \dfrac{\text{line A-B}}{\sin\theta} = \dfrac{\text{radius of earth}}{\sin\alpha}$

Applying the constants yeilds

$$\frac{6378.165 + h}{0.3902490997} = \frac{S}{\sin\theta} = \frac{6378.165}{\sin\alpha}$$

Apply the constraint that $\beta' + \theta + \alpha = 180^{o}$ which yields $\alpha = (22.97 - \theta)$

The expression then becomes

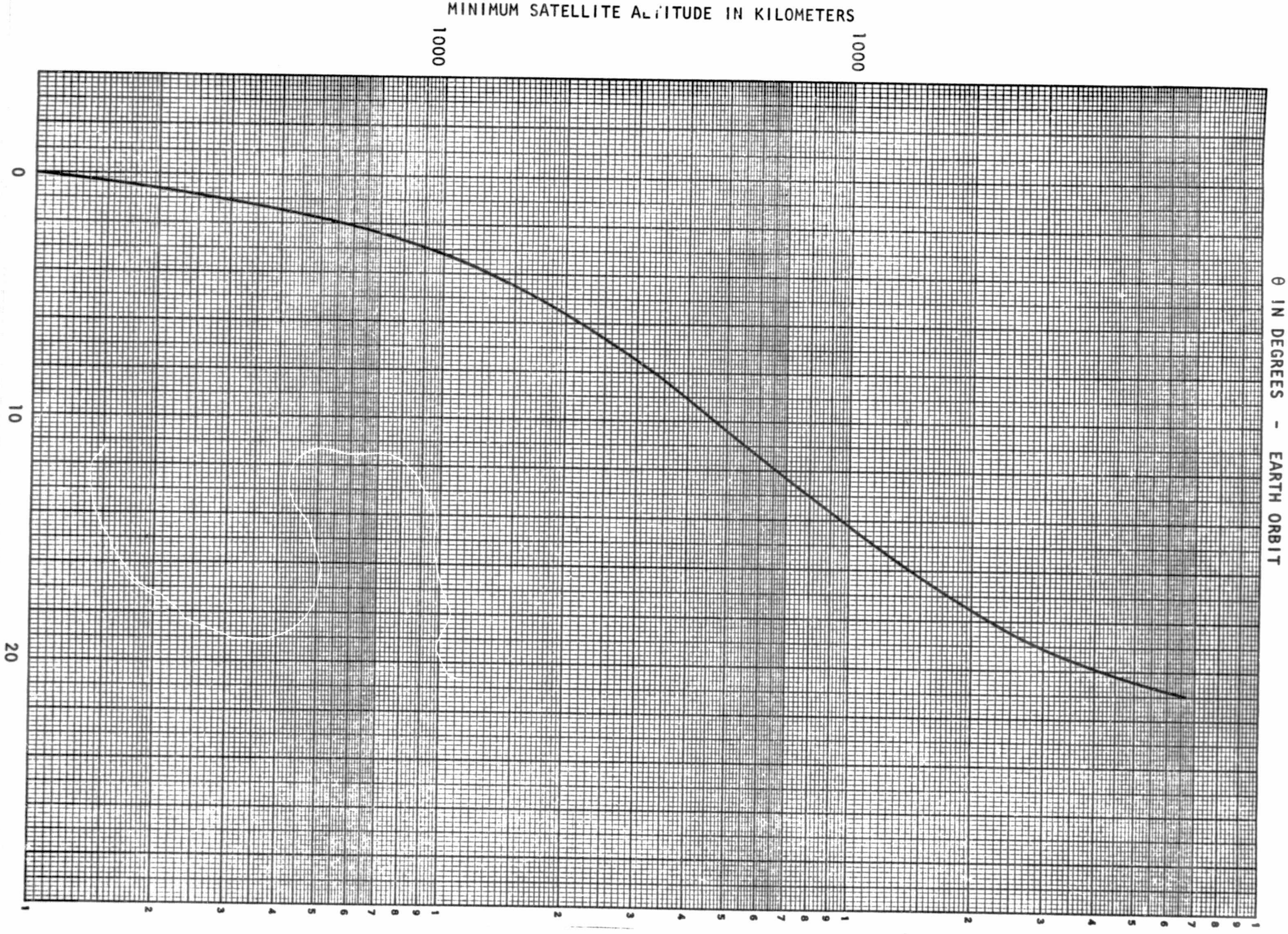
$$\frac{6378.165 + h}{0.3902490997} = \frac{6378.165}{\sin(22.97 - \theta)}$$ which reduces to

$$h = \frac{2489.073149}{\sin(22.97 - \theta)} - 6378.165$$

Using the expression for altitude as a function of θ yields the data of the following table which is plotted in the attached figure.

TABLE 1. MAXIMUM ACCEPTABLE ANGLE Θ AS A FUNCTION OF ALTITUDE

θ in Degrees	Altitude in KM	θ in Degrees	Altitude in KM
.5	134.33	11.0	5623.18
1.0	274.96	12.0	6701.91
1.5	422.32	13.0	7998.53
2.0	576.90	14.0	9585.90
2.5	739.23	15.0	11573.45
3.0	909.88	16.0	14133.42
3.5	1089.5	17.0	17553.45
4.0	1278.8	18.0	22352.70
4.5	1478.56	19.0	29573.36
5.0	1689.65	20.0	41661.32
5.5	1913.04	21.0	66028.68
6.0	2149.83	22.0	140652.97
6.5	2401.22	22.5	297057.98
7.0	2668.60	22.8	832525.34
7.5	2957.51	22.9	2030956.43
8.0	3257.71	22.95	7124291.31
8.5	3583.19	22.96	14254960.6
9.0	3932.24	22.965	28516299.41
9.5	4307.48	22.969	142607012.4
10.0	4711.94		


MINIMUM SATELLITE ALTITUDE IN KILOMETERS
1000
1000
θ IN DEGREES - EARTH ORBIT
0
10
20

APPENDIX C

INVESTIGATION PROCESS

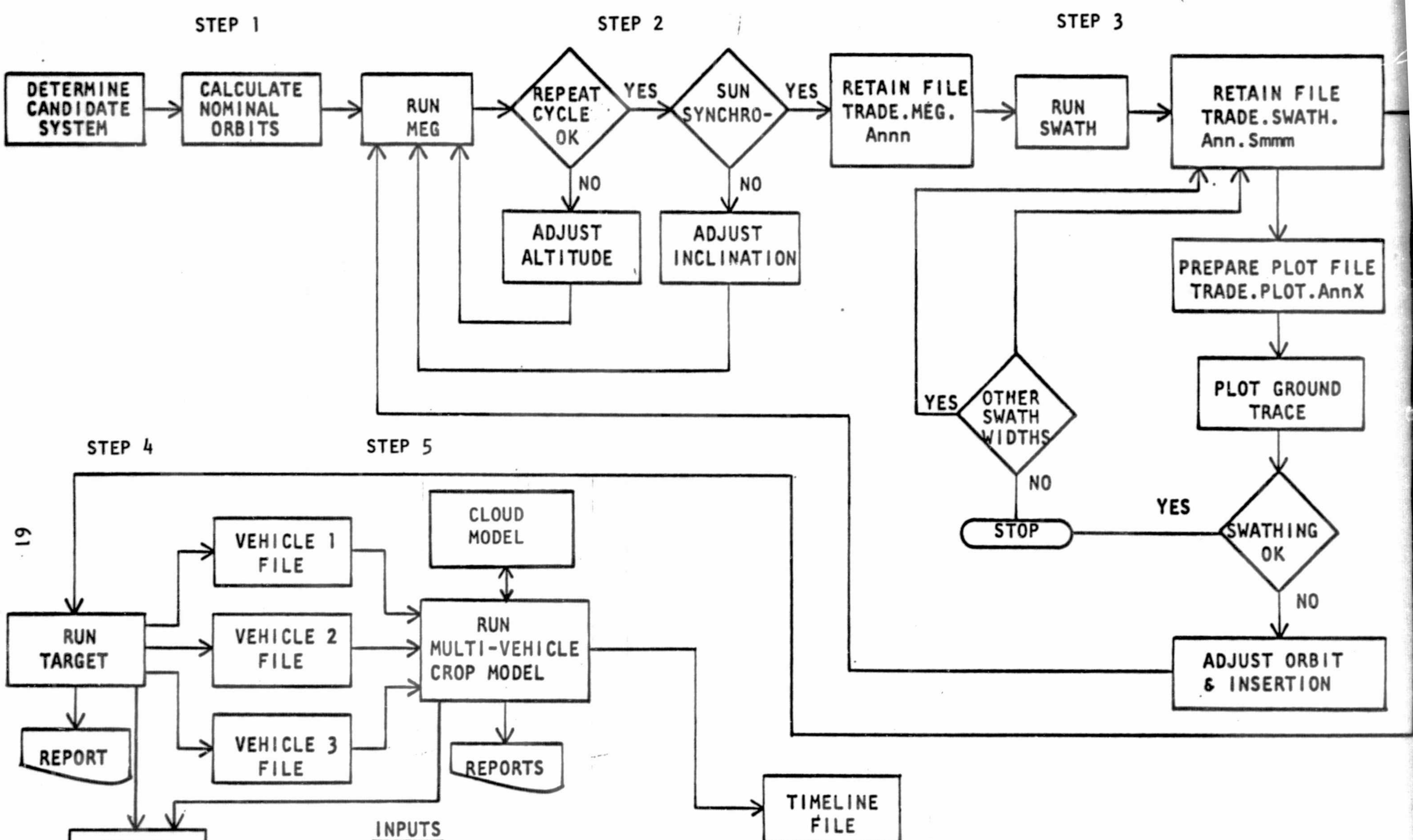
The sequence of steps involved in investigating each of the candidate systems is illustrated in Figure C-1.

STEP 1 - For each of the candidate systems, the orbit parameters were calculated using Reference 5.

STEP 2 - It was necessary to alter the nominal orbit parameters (altitude and inclination) slightly to obtain a repetition of the nadir equational crossing after the proper number of orbits. This was necessary because a one degree variation at the end of the repeat cycle is equivalent to a 111.32 KM error in the repeat swath at the equator. For all orbits except the 1485 KM orbit, the swath ground trace repeated with .75 KM. For economy of computer run time, the DSDS Mission Ephemeris Generator (MEG) was only run for one repeat cycle for each latitude and insertion point. The mission ephemerides, in terms of nadir latitude and longitude, were generated in along track increments of 90 nautical miles, which corresponds to the along track spacing of standard Landsat scenes. This permitted a direct accounting of scenes as a measure of data volume suitable for comparison with previous studies.

STEP 3 - The data generated by MEG was used to generate pairs of latitude and longitude corresponding to the edge of the sensor swath. For this study, nadir pointing was used exclusively. For increased swath width investigations, it was not necessary to repeat the MEG runs.

STEP 4 - The Target Model was run for each candidate system comprising a combination of satellites at different altitudes, insertion points and swath widths. This model determines, by target number, which targets are within the sensor swath for each



INPUTS

FOR EACH VEHICLE	o ALTITUDE o INCLINATION o SWATH WIDTH o ORBITS/REPEAT CYCLE o PERIOD	o ACCEPTABLE CLOUD CAT. FOR SCENE PROCESSING o OBSERVATION PROCESSED/WINDOW o SIMULATION START DAY o SIMULATION END DAY

FIGURE C-1. INVESTIGATION PROCESS

step (scene) during the complete repeat cycle. This data is saved for repeated use as input to the crop model. A typical report from the Target Model is shown in Figure C-2. The report shows how many times each target was seen during a repeat cycle and summarizes the results. As seen in Figure C-2, some targets are observed several times during a repeat cycle. This is due to overlap between adjacent swaths which, for a 185 KM swath, reaches 100% at 57.46^{o} latitude.

STEP 5 - The final step in the investigation of the candidate orbits involved running the Crop Model. For input data, the Crop Model will accept up to three Target Model output files. The following information required by the Crop Model is input on parameter cards:

- o Simulation Start Day
- o Simulation End Day
- o Number of observations of a target to be processed during a window. (A record is kept of the number of viewing opportunities and the number of opportunities that are cloud free. Only the number specified are placed in the time line file for processing)
- o Level of scene cloud cover acceptable for processing
- o The number of satellites, and for each satellite;
  - Altitude
  - Inclination
  - Number of orbits per repeat cycle
  - Period per orbit in seconds

For each test case, the simulation was a full year. When the end of the repeat cycle was reached on any of the input files, the file was rewound and reread until the full year was covered.

After a scene record was read from each satellite's input file, the following steps were performed.

A. A test was made to determine which scene occurred first.

B. A check was made to determine if any of the targets in the scene had crops in a growth stage of interest, i.e., an active window. If none of the targets were active, the next

INDEX	TARGET NUMBER	NUMBER OF OBSERVATIONS DURING REPEAT CYCLE
1287	846	1
1288	849	2
1289	1249	2
1290	1077	1
1291	1253	1
1292	1057	2
1293	1098	1
1294	1083	2
1295	1058	1
1296	1060	1
1297	844	1
1298	1245	1
1299	1072	1
1300	848	1
1301	850	1
1302	1159	2
1303	1256	1
1304	1055	1
1305	1166	2
1306	1163	1
1307	208	3
1308	1261	1

LISTING OF THE NUMBER OF OBSERVATIONS FOR EACH TARGET

```
THE NUMBER OF ASSIGNED TARGETS NOT OBSERVED =      0
THE NUMBER OF ASSIGNED TARGETS OBSERVED =       1533
THE PERCENT OBSERVED =100.00
THE NUMBER OF ASSIGNED TARGETS OBSERVED 1 TIME   =   800
THE NUMBER OF ASSIGNED TARGETS OBSERVED 2 TIMES =   635
THE NUMBER OF ASSIGNED TARGETS OBSERVED 3 TIMES =    18
THE NUMBER OF ASSIGNED TARGETS OBS .GT.3  TIMES =     0
```

SUMMARY DATA FOR ALL TARGETS

FIGURE C-2. TYPICAL OUTPUT FROM THE TARGET MODEL

scene was read from the corresponding input file and Step A was repeated.

C. If any of the targets in the scene were in an active window, the Cloud Model was called to determine the cloud category for the scene based on the current month, time of day and the cloud region.

D. For each target in an active window, the number of opportunities for observation was incremented.

E. The scene cloud cover was compared with the scene cloud cover threshold for processing. If the scene cloud cover was below the threshold, a test was made on each target in the scene. The percent of targets that could be obtained from a scene is a function of the scene cloud cover as shown below.

Scene Cloud Category	Percent of Cloud Cover in the Scene	Percent of Clear Samples Obtainable
1	10	95
2	10, 20, 30	80
3	40, 50	55
4	60, 70, 80, 90	25
5	100	0

A separate test was performed for each target. If the target was clear, the number of clear observations was incremented.

F. The Target Processing Timeline was created. For each clear observation, a test was made to see if the target had been seen for the desired number of times during the current window. If the desired number of clear observations had not been obtained, a record was written in the time line file with the following information:

- Target number
- Date
- Crop(s) of interest
- Window number

G. The Scene Processing Timeline was created. For each scene with at least one target in an active window, the following information was written into the time line file:

- Date
- Region number
- Cloud region
- Scene cloud category

At the end of the run, the Crop Model report generator was called. Typical outputs from the Crop Model report generators are described next.

CROP MODEL REPORTS

The next four figures show a portion of the reports from a typical Crop Model run. The first listing, shown in Figure C-3, contains the input parameters for the run. The case shown is for a one year run with 2 Landsat-D satellites. In this run, all scenes with 50% cloud cover or less were accepted for processing. The maximum number of observations to be processed for any target during a window was set at 2.

The scenes and sample segments acquired for processing on a daily basis are presented in Trade Study Report 1. A portion of Report 1 is shown in Figure C-4. The day of the year and date are given in the first 3 columns. The number of point targets (sample segments) to be processed for the day is listed in Column 4. For an operational system, this number would be scaled up by a factor of approximately 30. The next 5 columns show the number of scenes acquired in each cloud category. A scene is recorded only if there is at least one target in an active window within the sensor swath. The last three columns show the total scenes acquired for the day, the number of scenes with acceptable cloud cover and the percent of the total scenes that were acceptable. The last line of Trade Study Report 1 gives the yearly totals.

For the week starting August 27, as shown in Figure C-4, there were a total of 517 scenes acquired of which 337 had 50% cloud cover or less. From these scenes, 159 sample segments were extracted for processing. For an operational

THE INPUT PARAMETERS FOR THIS RUN ARE;

```
    1 = SIMULATION START DAY
  365 = SIMULATION END DAY
  233 = NUMBER OF ORBITS IN A REPEAT CYCLE FOR VEHICLE NUMBER 1
 5933 = NUMBER OF SECONDS IN AN ORBIT FOR VEHICLE NUMBER 1
98.20 = ORBIT INCLINATION IN DEGREES FOR VEHICLE NUMBER 1
  704 = ORBIT ALTITUDE IN KM. FOR VEHICLE NUMBER 1
  185 = SWATH WIDTH IN KM.  FOR VEHICLE NUMBER 1
  233 = NUMBER OF ORBITS IN A REPEAT CYCLE FOR VEHICLE NUMBER 2
 5933 = NUMBER OF SECONDS IN AN ORBIT FOR VEHICLE NUMBER 2
98.20 = ORBIT INCLINATION IN DEGREES FOR VEHICLE NUMBER 2
  704 = ORBIT ALTITUDE IN KM. FOR VEHICLE NUMBER 2
  185 = SWATH WIDTH IN KM.  FOR VEHICLE NUMBER 2
    3 = MAXIMUM CLOUD CATEGORY ACCEPTED FOR PROCESSING
    2 = MAXIMUM NUMBER OF OBS. PROCESSED DURING A WINDOW
```

FIGURE C-3. LISTING OF INPUT PARAMETERS FOR A CROP MODEL RUN

TS REPORT 1 - FILE 27 TIMELINE DATA

DAY	MONTH	DAY	POINT TARGETS OBSERVED	SCENES OBSERVED BY CLOUD CATEGORY CC 1	CC 2	CC 3	CC 4	CC 5	TOTAL SCENES	SCENES ACCEPTED FOR PROC	PERCENT ACC FOR PROCESSING
1	1	1	2	0	1	0	0	2	3	1	33.3
2	1	2	7	0	2	2	1	0	5	4	80.0
3	1	3	0	0	0	0	0	0	0	0	0.0
4	1	4	12	1	2	0	2	1	6	3	50.0
5	1	5	3	0	1	0	1	0	2	1	50.0
6	1	6	9	4	4	0	2	1	11	8	72.7
7	1	7	11	1	1	0	0	0	2	2	100.0
•											
•											
•											
239	8	27	21	11	25	13	21	3	73	49	67.1
240	8	28	31	21	25	12	27	5	90	58	64.4
241	8	29	14	13	18	8	23	7	69	39	56.5
242	8	30	19	15	23	8	24	6	76	46	60.5
243	9	1	39	16	18	18	18	3	73	52	71.2
244	9	1	23	11	15	7	20	3	56	33	58.9
245	9	2	12	24	22	14	16	4	80	60	75.0
•											
•											
•											
359	12	25	2	1	3	0	4	0	8	4	50.0
360	12	26	0	1	0	1	3	0	5	2	40.0
361	12	27	0	1	4	2	0	1	8	7	87.5
362	12	28	0	3	1	0	4	1	9	4	44.4
363	12	29	0	1	3	4	1	1	10	8	80.0
364	12	30	1	1	5	0	3	0	9	6	66.7
365	1	1	0	2	1	0	4	1	8	3	37.5
	TOTAL		5495	1912	2852	1612	3015	645	10036	6376	63.5

FIGURE C-4. SAMPLE SEGMENT AND SCENE ACQUISITION TIME LINE

system, this would equate to 159 x 30 = 4770 sample segments and represents a processing load of 954 sample segments per day for a 5-day week.

A summary of the scenes observed for the year in each region is shown in Figure C-5. The information presented is the same as that contained in the last 8 columns of Trade Study Report 1. There were no scenes acquired for Region 31 (USA E) because none of the four major crops grew in sufficient quantities in this region; therefore, no targets were assigned to the region. The percent of scenes with 50% cloud cover or less ranged from a low of 44.7% in the central region of India to a high of 84.8% in Egypt.

Figure C-6 is typical of the reports for each phenological* region. For each target assigned to the region, the following information is given:

- Phenological Region Number - The 36 geographic regions on Table 2, page 6, were further divided into 58 homogeneous phenological regions, and with a unique crop calendar.
- Target Number - Target numbers were assigned consecutively in each country.
- Cloud Region - Specifies which of the 30 cloud model regions the target is in.
- Latitude and Longitude.
- For each window during which observations are to be obtained, five additional pieces of information are given:
  - Crop Code - A one in any of the five columns under the crop code means that an image during the window is used to discriminate that crop from other crops in the region. (The crop code is defined on the second line of the report.)
  - Start - Is the day of the year on which the window starts.
  - LEN - Is the number of days that the window is active beyond the start day.
  - OBS - Is the number of times that the target was within the swath of the satellite's sensor during the window, i.e., the number of observation opportunities regardless of cloud cover.

*These phenological regions are regions with equivalent climates, soil conditions, and cropping practices that may be characterized by a single crop calendar.

REGION NUMBER	NAME	SCENES OBSERVED BY CLOUD CATEGORY CC 1	CC 2	CC 3	CC 4	CC 5	TOTAL SCENES	SCENES ACCEPTED FOR PROC	PERCENT ACC FOR PROCESSING
1	ARGENTNA	73	105	33	85	17	313	211	67.4
2	AUSTRLIA	50	49	15	40	6	160	114	71.2
3	BANGLDSH	9	24	15	26	5	79	48	60.8
4	BRAZIL N	36	62	40	79	9	226	138	61.1
5	BRAZIL S	46	76	35	103	23	283	157	55.5
6	CANADA	38	141	39	126	18	362	218	60.2
7	CHINA N	37	169	45	204	28	483	251	52.0
8	CHINA C	153	179	55	178	39	604	387	64.1
9	CHINA S	51	66	21	65	12	215	138	64.2
10	EGYPT	42	35	18	15	2	112	95	84.8
11	FRANCE	60	85	75	95	24	339	220	64.9
12	IND PUNJ	28	37	15	21	3	104	80	76.9
13	IND GANG	10	29	19	37	12	107	58	54.2
14	IND CENT	20	37	31	85	24	197	88	44.7
15	IND BILA	15	25	21	40	12	113	61	54.0
16	IND COST	30	53	36	82	19	220	119	54.1
17	INDONESA	30	54	33	49	7	173	117	67.6
18	ITALY	70	75	69	74	11	299	214	71.6
19	JAPAN	18	25	27	38	7	115	70	60.9
20	MEXICO	92	160	80	162	40	534	332	62.2
21	PAKISTAN	23	32	8	24	4	91	63	69.2
22	RUMANIA	41	47	27	39	11	165	115	69.7
23	S.AFRICA	26	35	18	40	13	132	79	59.8
24	PHILPNES	44	41	26	74	18	203	111	54.7
25	THAILAND	13	36	31	60	11	151	80	53.0
26	TURKEY	31	22	45	28	3	129	98	76.0
27	U.S. A	69	84	49	97	21	320	202	63.1
28	U.S. B	78	93	80	101	32	384	251	65.4
29	U.S. C	130	164	125	159	35	613	419	68.4
30	U.S. D	94	119	42	142	35	432	255	59.0
31	U.S. E	0	0	0	0	0	0	0	0.0
32	USSR LAT	134	167	127	152	38	618	428	69.3
33	USSR UKR	25	51	29	48	10	163	105	64.4
34	USSR T-V	116	106	101	95	17	435	323	74.3
35	USSR V-U	92	153	94	168	39	546	339	62.1
36	USSR SIB	47	158	47	139	23	414	252	60.9
37	YUGOSLAV	41	58	41	45	17	202	140	69.3

FIGURE C-5. SUMMARY OF SCENES OBSERVED BY REGION AND CLOUD CATEGORY FOR THE YEAR

TRADE STUDY REPORT 2 - POINT TARGET DATA

FRANCE FRANCE FRANCE FRANCE CROP CODE = ZWCSR Z=SPRING WHEAT W=WINTER WHEAT C=CORN S=SOYBEANS R=RICE

PHENO REGION	TARGET NUMBER	CLOUD REGION	LATITUDE	LONG	WINDOW 1 CROP CODE ZWCSR	START	LEN	OBS	CLR	PERCENT CLEAR	WINDOW 2 CROP CODE ZWCSR	START	LEN	OBS	CLR	PERCENT CLEAR	WINDOW 3 CROP CODE ZWCSR	START	LEN	OBS	CLR	PERCENT CLEAR
11	429	11	138.08	4.30	1000	120	31	6	2	33.3	100	162	59	12	4	33.3						
11	430	11	133.14	359.97	1000	120	31	4	1	25.0	100	162	59	8	4	50.0						
11	431	11	133.63	4.90	1000	120	31	6	5	83.3	100	162	59	12	7	58.3						
11	432	11	139.81	2.47	1000	120	31	6	2	33.3	100	162	59	12	9	75.0						
11	433	11	137.70	358.17	1000	120	31	6	1	16.7	100	162	59	10	5	50.0						
11	434	11	140.80	2.79	1000	120	31	6	3	50.0	100	162	59	12	6	50.0						
11	435	11	135.27	2.88	1000	120	31	8	4	50.0	100	162	59	16	9	56.3						
11	436	11	133.84	2.92	1000	120	31	4	1	25.0	100	162	59	8	3	37.5						
11	437	11	139.88	4.14	1000	120	31	6	4	66.7	100	162	59	12	4	33.3						
11	438	11	135.62	359.68	1000	120	31	8	2	25.0	100	162	59	16	8	50.0						
11	439	11	139.77	1.60	1000	120	31	8	5	62.5	100	162	59	16	8	50.0						
11	440	11	140.14	2.65	1000	120	31	6	4	66.7	100	162	59	12	7	58.3						
11	441	11	136.38	3.07	1000	120	31	8	2	25.0	100	162	59	16	8	50.0						
11	442	11	138.58	3.90	1000	120	31	8	5	62.5	100	162	59	16	9	56.3						
11	443	11	140.69	1.79	1000	120	31	8	3	37.5	100	162	59	16	13	81.3						
11	444	11	134.40	6.25	1000	120	31	4	4	100.0	100	162	59	8	1	12.5						
11	445	11	136.48	0.70	1000	120	31	4	1	25.0	100	162	59	8	4	50.0						
11	446	11	134.24	3.14	1000	120	31	4	2	50.0	100	162	59	8	3	37.5						
11	447	11	138.64	7.32	1000	120	31	8	6	75.0	100	162	59	16	10	62.5						
11	448	11	139.28	5.88	1000	120	31	8	4	50.0	100	162	59	16	8	50.0						
11	449	11	139.70	1.83	1000	120	31	8	4	50.0	100	162	59	16	10	62.5						
11	450	11	137.91	0.32	1000	120	31	6	2	33.3	100	162	59	12	7	58.3						
11	451	11	136.27	359.19	1000	120	31	6	3	50.0	100	162	59	11	7	63.6						
11	452	11	137.50	1.08	1000	120	31	4	3	75.0	100	162	59	8	3	37.5						
11	453	11	140.31	3.69	1000	120	31	8	3	37.5	100	162	59	16	6	37.5						
11	454	11	138.38	357.22	1000	120	31	6	1	16.7	100	162	59	11	4	36.4						
11	455	11	139.73	2.34	1000	120	31	6	3	50.0	100	162	59	12	6	50.0						
11	456	11	133.28	2.40	1000	120	31	6	3	50.0	100	162	59	12	5	41.7						
11	457	11	138.45	3.68	1000	120	31	8	2	25.0	100	162	59	16	8	50.0						
11	458	11	134.22	3.91	1000	120	31	8	2	25.0	100	162	59	16	10	62.5						
11	459	11	133.49	358.87	1000	120	31	4	1	25.0	100	162	59	8	3	37.5						
11	460	11	138.80	6.91	1000	120	31	8	5	62.5	100	162	59	16	10	62.5						
11	461	11	134.14	7.42	1000	120	31	6	3	50.0	100	162	59	10	5	50.0						
11	462	11	133.24	0.32	1000	120	31	6	2	33.3	100	162	59	12	6	50.0						
11	463	11	133.78	4.64	1000	120	31	4	4	100.0	100	162	59	8	5	62.5						
11	464	11	137.39	359.01	1000	120	31	6	0	0.0	100	162	59	10	7	70.0						
11	465	11	134.96	0.75	1000	120	31	6	4	66.7	100	162	59	12	6	50.0						
11	466	11	135.00	5.67	1000	120	31	8	5	62.5	100	162	59	16	7	43.8						
11	467	11	139.45	5.10	1000	120	31	6	2	33.3	100	162	59	12	6	50.0						
11	468	11	139.02	0.73	1000	120	31	6	3	50.0	100	162	59	12	10	83.3						
11	469	11	139.79	4.43	1000	120	31	8	5	62.5	100	162	59	16	12	75.0						
11	470	11	137.11	358.59	1000	120	31	6	3	50.0	100	162	59	10	7	70.0						
11	471	11	136.24	358.98	1000	120	31	6	3	50.0	100	162	59	11	6	54.5						
11	472	11	134.99	3.81	1000	120	31	6	3	50.0	100	162	59	12	6	50.0						
11	473	11	134.27	5.29	1000	120	31	8	5	62.5	100	162	59	16	8	50.0						
			TOTALS FOR WINDOW 1 - 2 ARE:					286	135	47.2				561	300	53.5						

45 SAMPLES IN THIS REGION
0 WINDOWS HAD ZERO OPPORTUNITIES
1 WINDOWS HAD ZERO CLOUD FREE OBSERVATIONS

ORIGINAL PAGE IS OF POOR QUALITY

FIGURE C-6. TYPICAL REPORT FOR TARGETS IN A PHENOLOGICAL REGION

- CLR - Is the number of times that a clear (cloud-free) observation was obtained during the window.
- Percent Clear - Is the percent of the total observational opportunities which were clear.

At the bottom of the report, the number of observational opportunities and the number of clear observations are totaled for each window. The percent of the total opportunities that were clear is also given.

A summary of the number of targets in the region, the number of windows that did not achieve at least one observational opportunity and the number of windows that did not achieve at least one cloud free observation are also given. For the example shown, all targets had observational opportunities and only Target Number 474 failed to have at least one cloud free observation.

During the first window, shown in Figure C-6, each target was observed either 4, 6, or 8 times. In this run, there were two satellites, each with a 16-day repeat cycle. Since the window has a 32-day duration, each satellite would see each target twice exclusive of overlap coverage. If a target was in the overlap coverage area for one satellite, it would be observed six times, and if a target was in the overlap coverage area for both satellites, it would be observed eight times.

STANDARD TEST CONDITIONS

For all test cases to be discussed, the following conditions are standard unless otherwise specified:

- Swath Width - A standard Landsat sensor with a swath width of 185 KM (100 Nautical Miles) was used.
- Scene - A scene represents an area one swath width wide with an along track distance of 90 Nautical Miles.
- Cloud Cover Accepted for Processing - All scenes with less than or equal to 50% cloud cover were accepted by the preprocessor for sample segment extraction.

- Observations Processed per Window - Only one clear observation was required during each window. For regions with multiple crops, a separate window was defined to discriminate each crop from the other major crops and confusion crops.

The various test cases are compared on their capability of obtaining needed sample segments. The goal for acquisition of samples was set at 98% of the designate samples for each region. This level was set to minimize the mensuration error and the introduction of bias caused by obtaining a disporportionate share of samples from areas that are relatively cloud free.

APPENDIX D

CLOUD MODEL & STATISTICS

The Cloud Model used in this simulation is identical to the cloud model used in a previous study. It is described in detail in Reference 3, "Global Crop Production Forecasting Trade Study - Volume II - Approach and Results," Section 4-14.

Tables 1 and 2 present cloud statistics based on the twenty year runs with two Landsat-D satellites. Table 1 gives the mean and standard deviation for the percent of clouds in cloud categories 1 through 3 (less than 50% cloud cover) for each region. Table 2 contains the mean and standard deviation for the 20 year period regardless of region. On the average, 63.2% of the scenes had 50% cloud cover or less.

TABLE 1. MEAN AND STANDARD DEVIATION OF THE PERCENT OF SCENES WITH 50% CLOUD COVER OR LESS

REGION NUMBER	NAME	PERCENT OF SCENES IN CLOUD CATEGORIES 1-3	
		MEAN	STANDARD DEVIATION
1	Argentina	67.5	2.3
2	Australia	76.6	3.2
3	Bangladesh	52.8	5.5
4	Brazil North	61.7	3.3
5	Brazil South	57.2	3.0
6	Canada	55.7	2.5
7	China North	50.7	2.5
8	China Central	64.0	2.2
9	China South	66.3	3.0
10	Egypt	86.8	3.1
11	France	66.9	2.8
12	India Punjab	71.4	4.5
13	India Ganges	47.8	6.6
14	India Central	46.2	3.2
15	India Bilaspur	50.5	4.6
16	India Costal	58.1	3.5
17	Indonesia	63.4	4.2
18	Italy	68.8	2.6
19	Japan	57.2	4.9
20	Mexico	64.5	1.9
21	Pakistan	69.6	5.3
22	Romania	66.8	3.6
23	South Africa	66.8	3.6
24	Philippines	52.5	3.1
25	Thailand	57.7	3.9
26	Turkey	69.1	3.9
27	USA - Region A	65.7	3.1
28	USA - Region B	68.1	1.9
29	USA - Region C	66.6	2.0
30	USA - Region D	59.5	2.7
31	USA - Region E		
32	USSR Latvia	67.7	2.0
33	USSR Ukraine	67.0	4.6
34	USSR Transvolga	69.9	2.3
35	USSR Volga-Ural	65.9	1.4
36	USSR Siberia	56.4	2.4
37	Yugoslavia	66.3	2.2

TABLE 2. MEAN AND STANDARD DEVIATION FOR THE OCCURRENCE OF EACH CLOUD CATEGORY.

Cloud Category	Percent of Cloud Cover	PERCENT OF SCENES IN CATEGORY	
		Mean	Standard Deviation
1	0	19.5	0.26
2	10, 20, 30	27.9	0.35
3	40, 50	15.8	0.30
4	60, 70, 80, 90	30.0	0.40
5	100	6.8	0.29
1 - 3	0 - 50	63.2	0.40